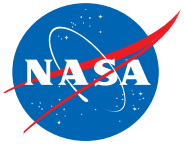


Numerical Simulations of a Quiet SuperSonic Technology (QueSST) Aircraft Preliminary Design

David Friedlander, Christopher Heath, and Raymond Castner

(NASA Glenn Research Center)

Outline

- Introduction
- Geometry and Numerical Modeling
- Results
- Summary
- Conclusions

Introduction (Part 1)

- NASA has a new X-plane mission: the Low-Boom Flight Demonstration.
  - The QueSST aircraft preliminary design is the intended design to move forward for the Low Boom Flight Demonstrator X-Plane.
  - The aircraft, designed at Lockheed Martin, was tested for aerodynamics and propulsion at the NASA Glenn Research Center (GRC) 8’x6’ supersonic wind tunnel in the first half of 2017.

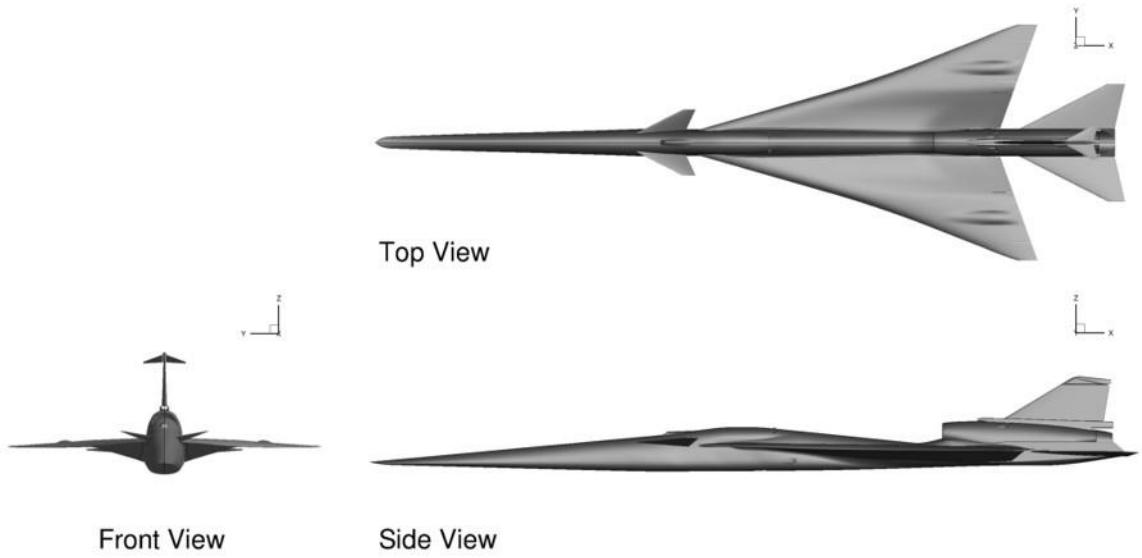
Introduction (Part 2)

- This presentation will focus on the 3D RANS Computational Fluid Dynamic (CFD) analyses that were performed on one of the vehicle configurations tested.
  - The purpose of the simulations was to help determine internal “best practices” for predicting inlet performance of a top-aft-mounted inlet.

Geometry and Numerical Modeling

Geometry

- Simulations used a 9.5% scale version of the full aircraft geometry, including the C607 version of the inlet.
- Due to left/right symmetry, only half of the vehicle was modeled.



Flow Solver

- FUN3D was used for all CFD simulations.
  - Node-based, unstructured production level code developed and maintained at the NASA Langley Research Center.
  - Can solve 2D/3D Euler and RANS equations.
  - Can perform adjoint-based mesh refinement.

Parameter Matrix

- The following combinations of parameters were tried:

Case #	Boundary-Layer Cell Type	Adaptation Approach	Adaptation Cycles
1	Tetrahedral	NA	0
2	Tetrahedral	Linear Pressure Sensor	8
3	Pentahedral	NA	0
3A*	Pentahedral	NA	0
4	Pentahedral	Pressure Box	8
5	Tetrahedral	Pressure Box	8**
6	Tetrahedral	Pressure Box	16**
7	Pentahedral	Pressure Box	8**
8	Pentahedral	Pressure Box	16**
9	Tetrahedral	Manual	0
10	Pentahedral	Manual	0

**reduced number of additional nodes/ adaptation cycle.

*smoothed version of case #3.

Initial/Manually Refined Grids (Procedure)

- Pointwise grid generation software was used to generate an unstructured surface grid.
- The AFLR3 code was used to generate the unstructured volume grids.
  - Code is developed and maintained at the Mississippi State University.
  - Uses the Advancing Front/Local Reconstruction method.

Initial/Manually Refined Grids (Information)

- Grid Sizes:

Boundary-Layer Cell Type	Number of Nodes
Initial Tetrahedral	33.4 Million
Initial Pentahedral	33.4 Million
Manually Refined Tetrahedral	92.3 Million
Manually Refined Pentahedral	91.8 Million

- Spacing off of the viscous surfaces for the initial grids was such that $y^+ < 0.2$.

Flow Conditions

- Three different set points from the 8’x6’ wind tunnel test were chosen for comparison:

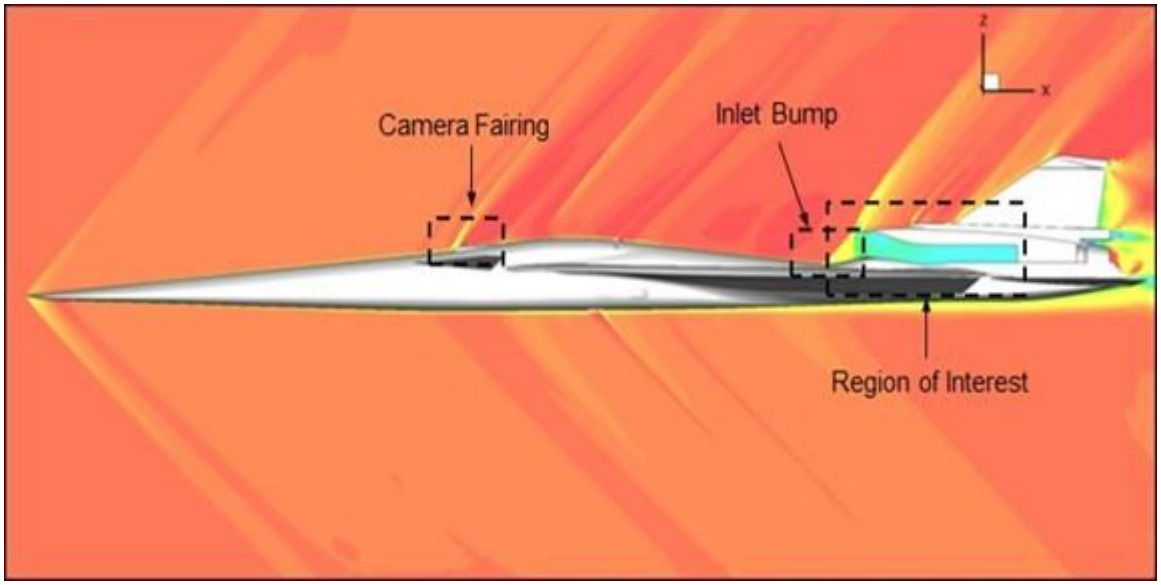
Mach Number	Angle of Attack (α, degrees)	Angle of Sideslip (β, degrees)
1.46	2.0	0.0
1.35	3.0	0.0
0.30	3.0	0.0

- The Spalart-Allmaras (SA) turbulence model was used for all simulations.

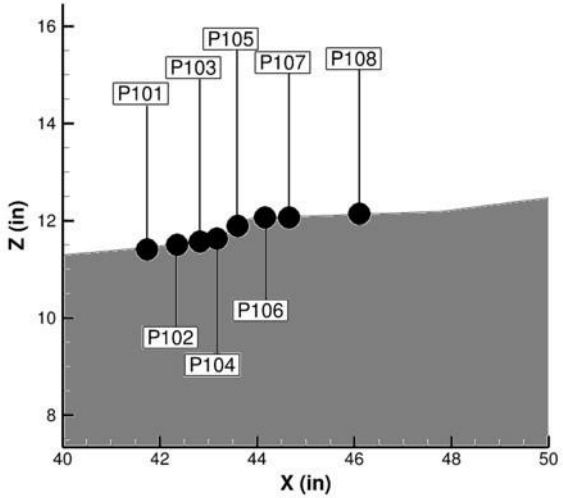
Results

- Station Locations
- Substudies:
  - Cell Type and Grid Adaptation Metric
  - Number of Adaptation Cycles
  - Manual Refined Grids
  - Additional Simulations

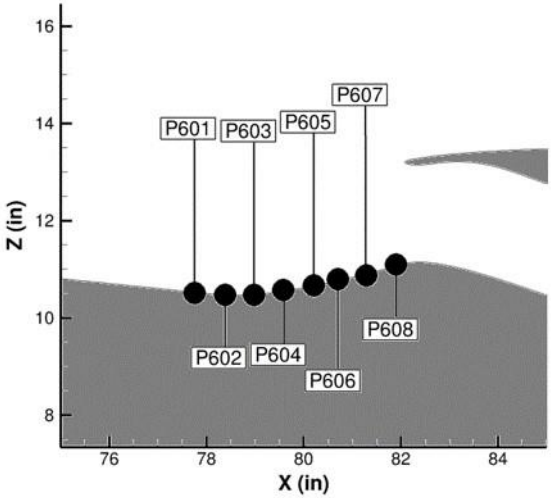
Station Locations



Camera Fairing Region

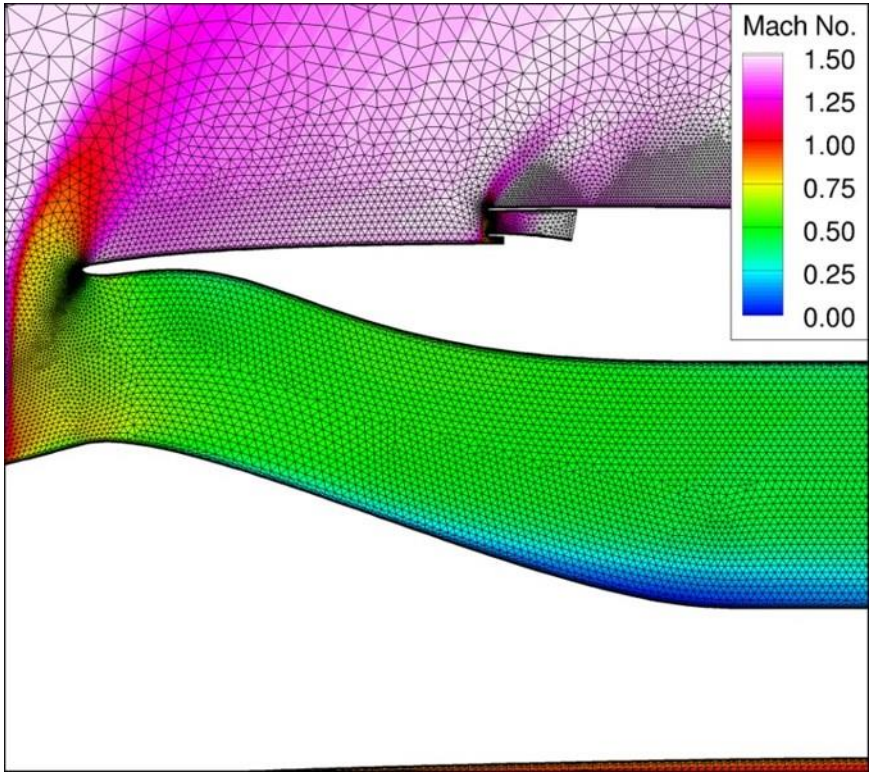


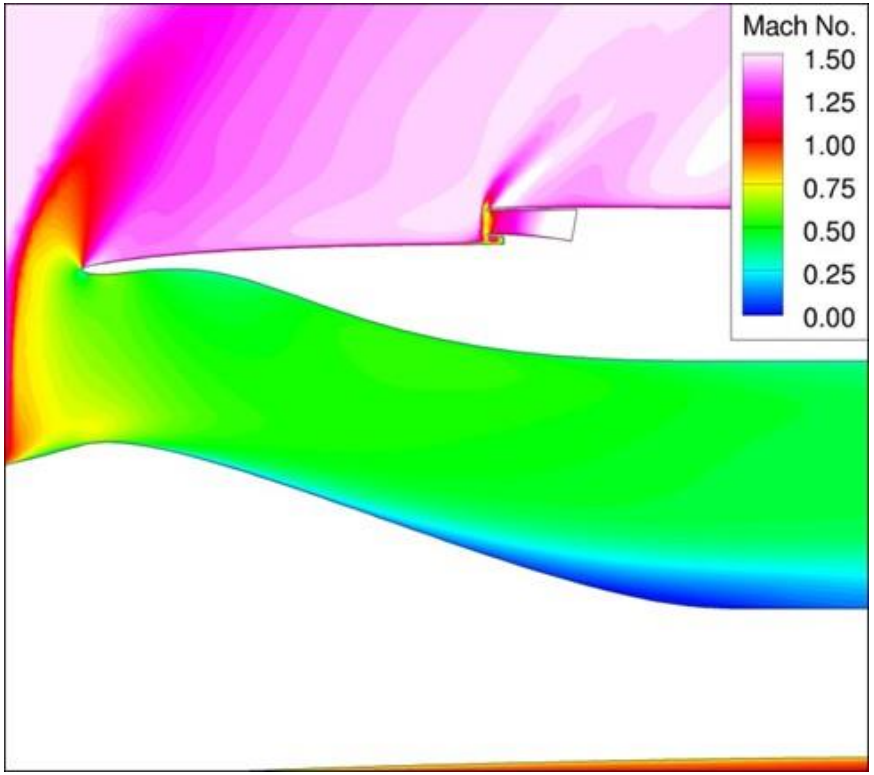
Inlet Bump Region



Cell Type and Grid Adaptation Metric

$M_\infty = 1.46$

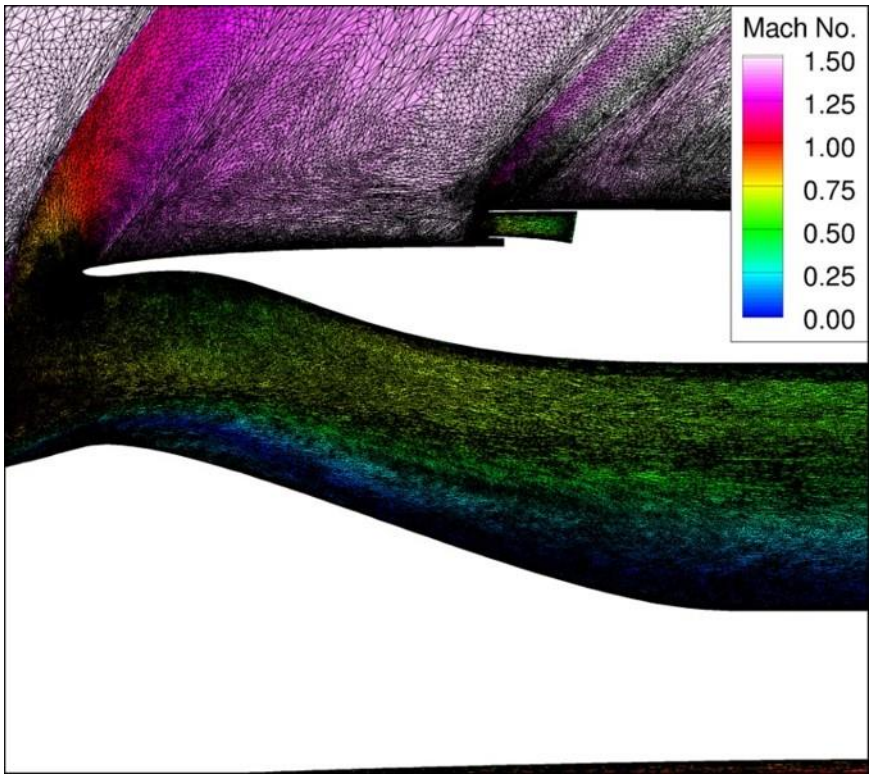


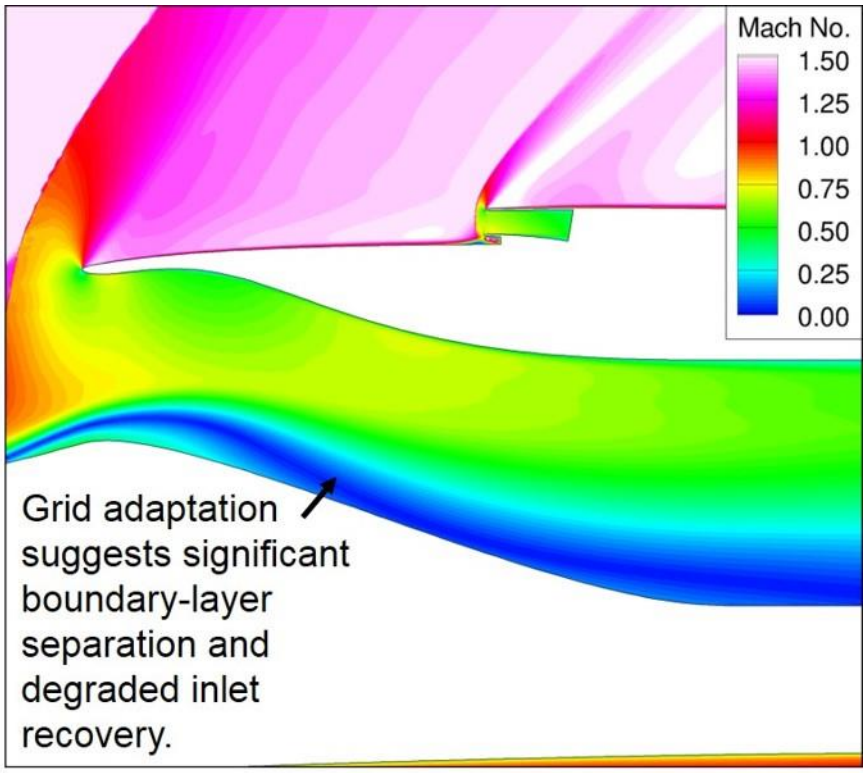


Initial tetrahedral boundary-layer grid (Case #1)

Cell Type and Grid Adaptation Metric

$M_\infty = 1.46$

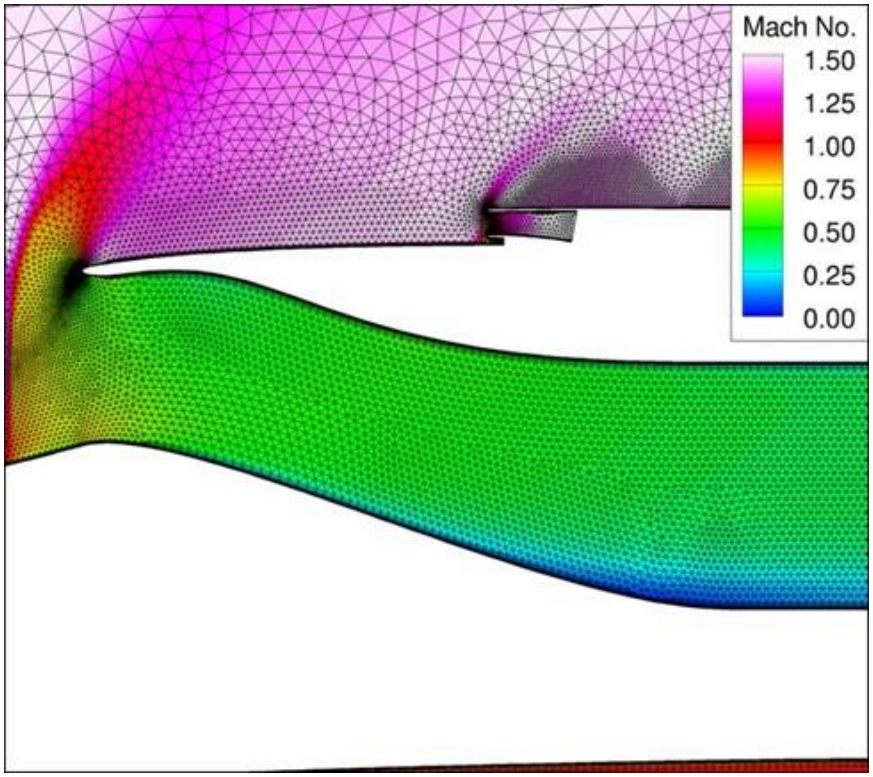


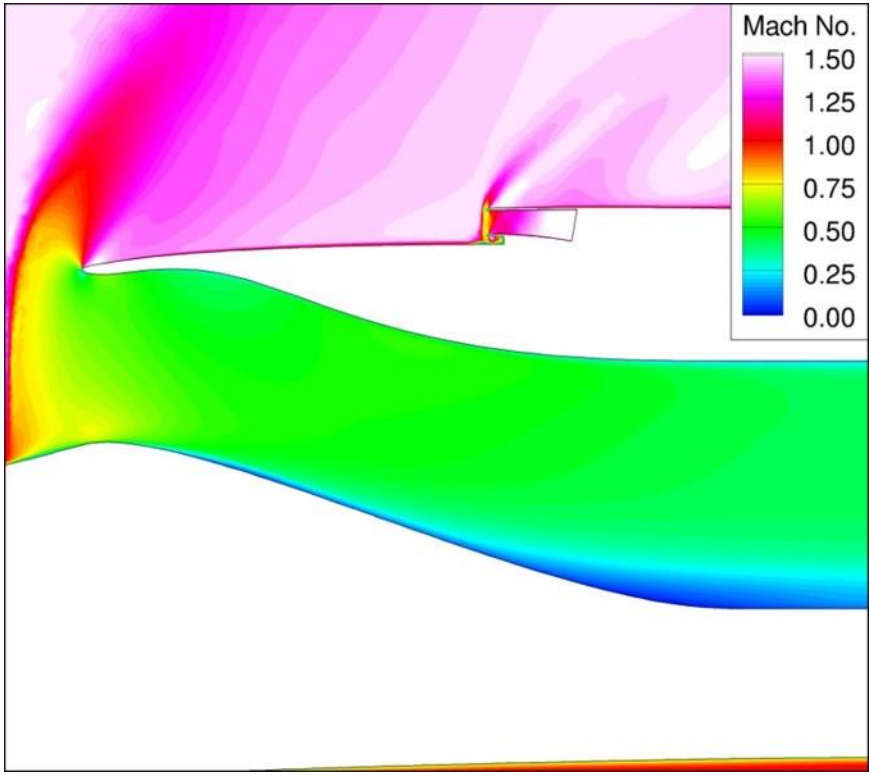


8 adaptation cycle tetrahedral boundary-layer grid (Case #2)
(Linear Pressure Sensor)

Cell Type and Grid Adaptation Metric

$M_\infty = 1.46$

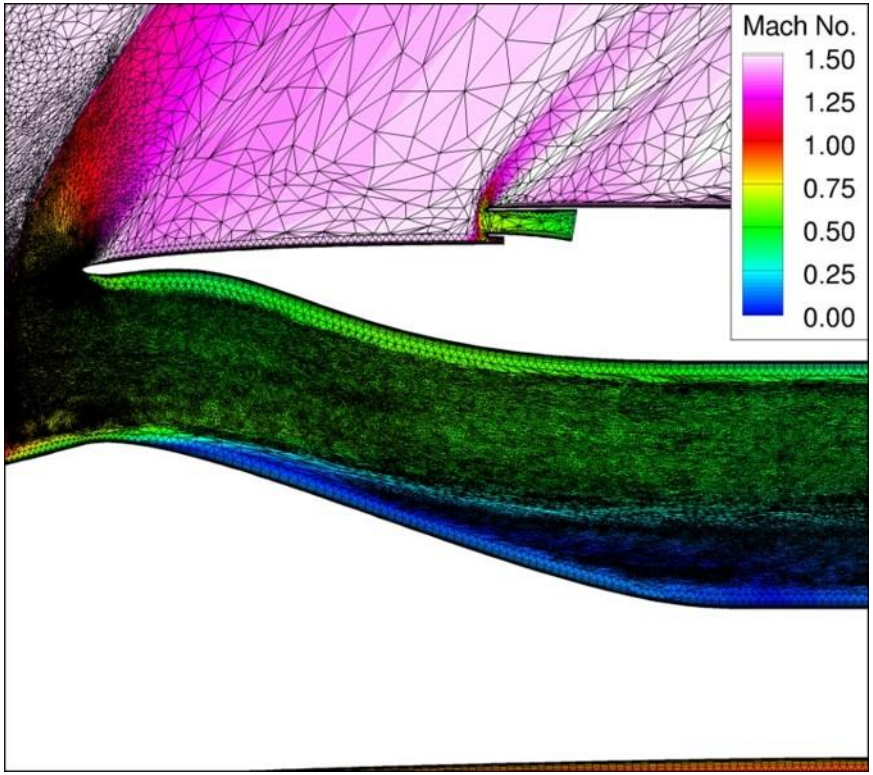


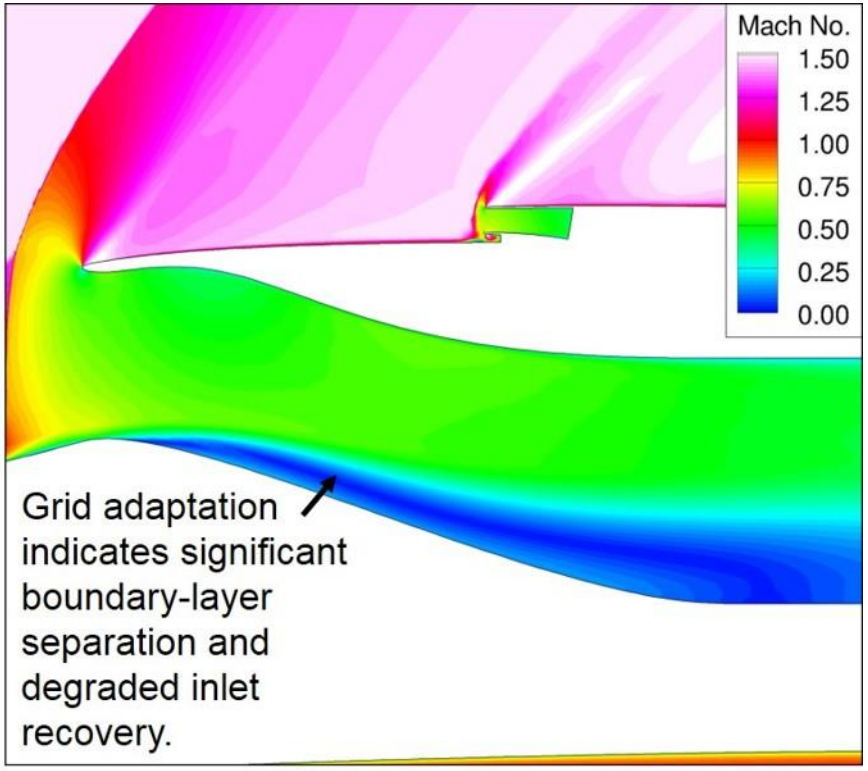


Initial pentahedral boundary-layer grid (Case #3)

Cell Type and Grid Adaptation Metric

$M_\infty = 1.46$

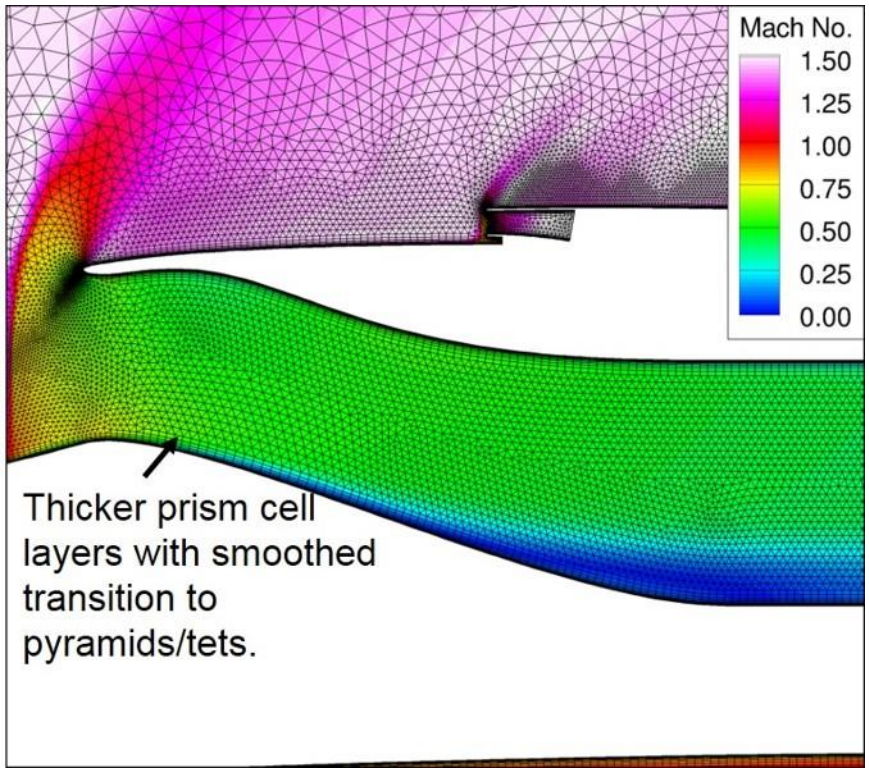


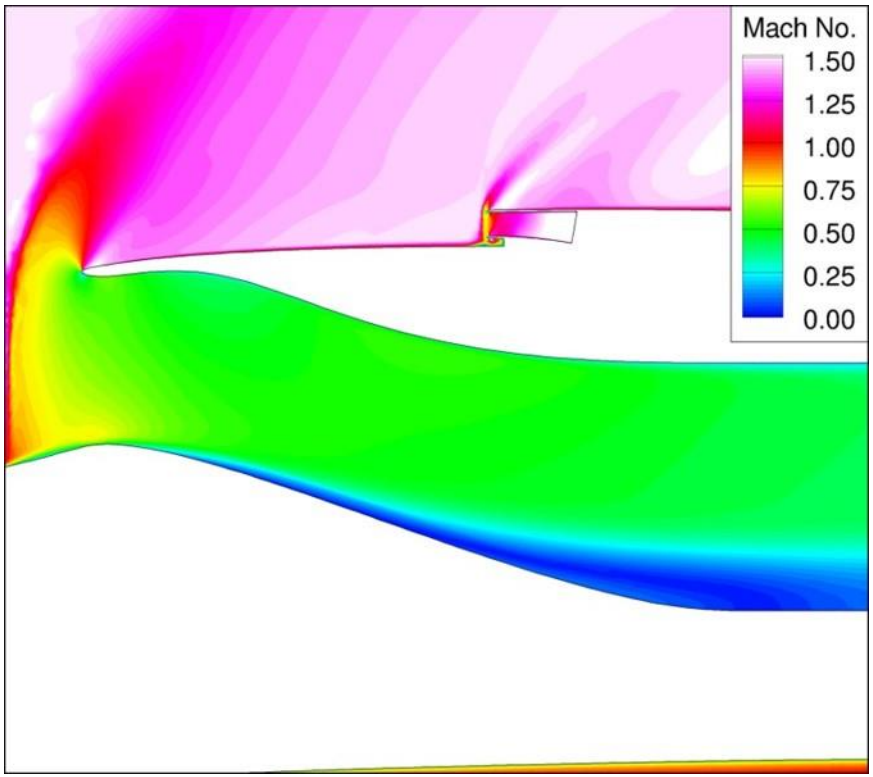


8 adaptation cycle pentahedral boundary-layer grid (Case #4)
(Pressure Box)

Cell Type and Grid Adaptation Metric

$M_\infty = 1.46$

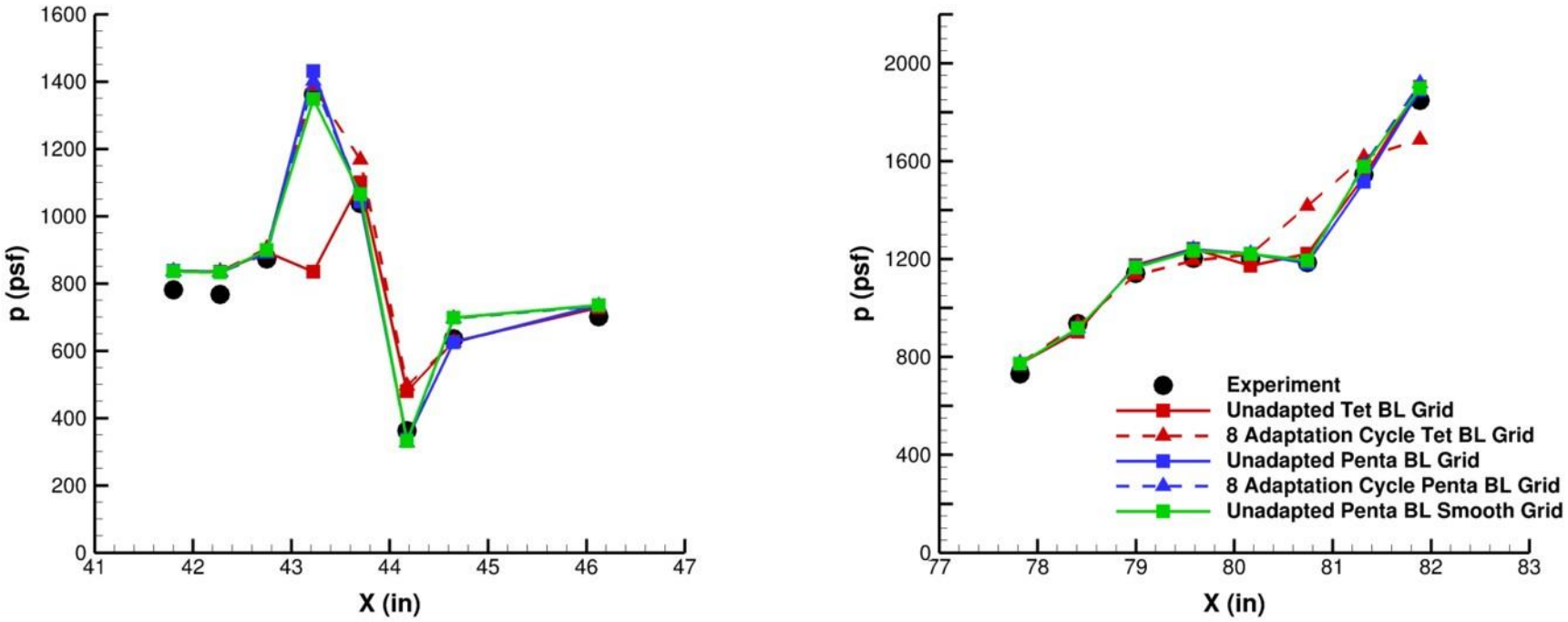




Initial pentahedral boundary-layer smooth grid (Case #3A)

Cell Type and Grid Adaptation Metric

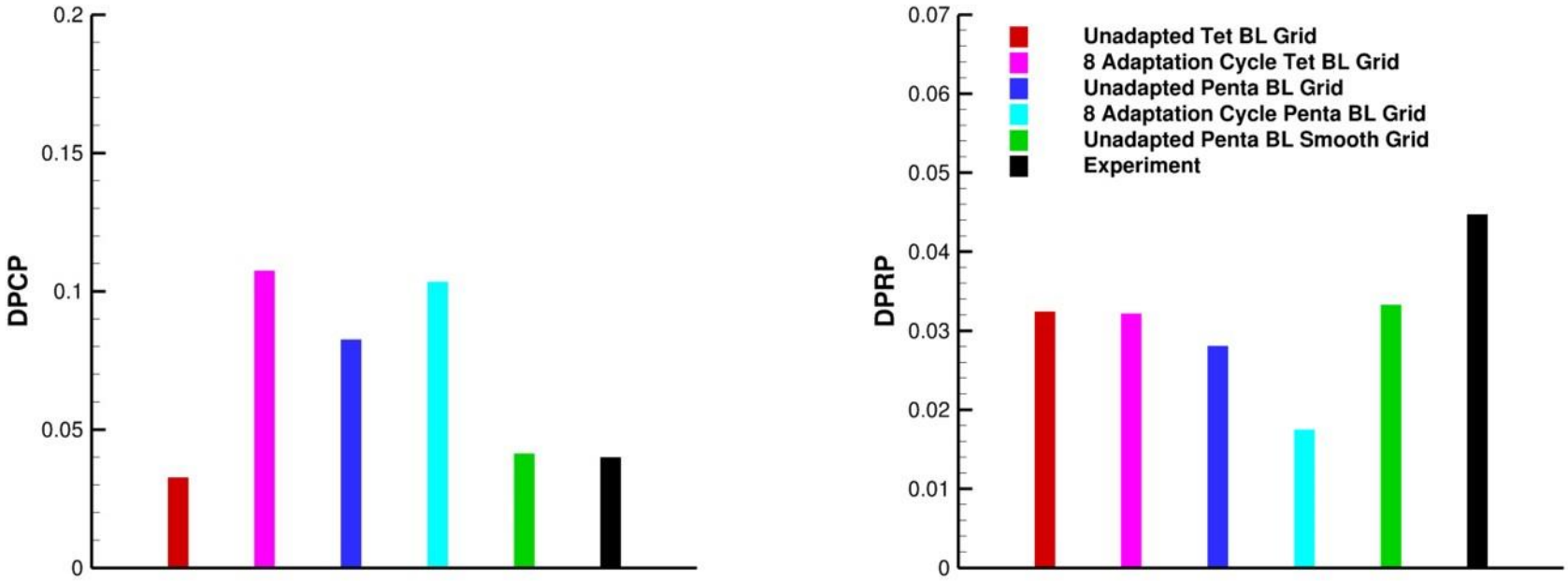
$M_\infty = 1.46$



Pressure measurements at the camera fairing (left) and inlet bump (right) regions

Cell Type and Grid Adaptation Metric

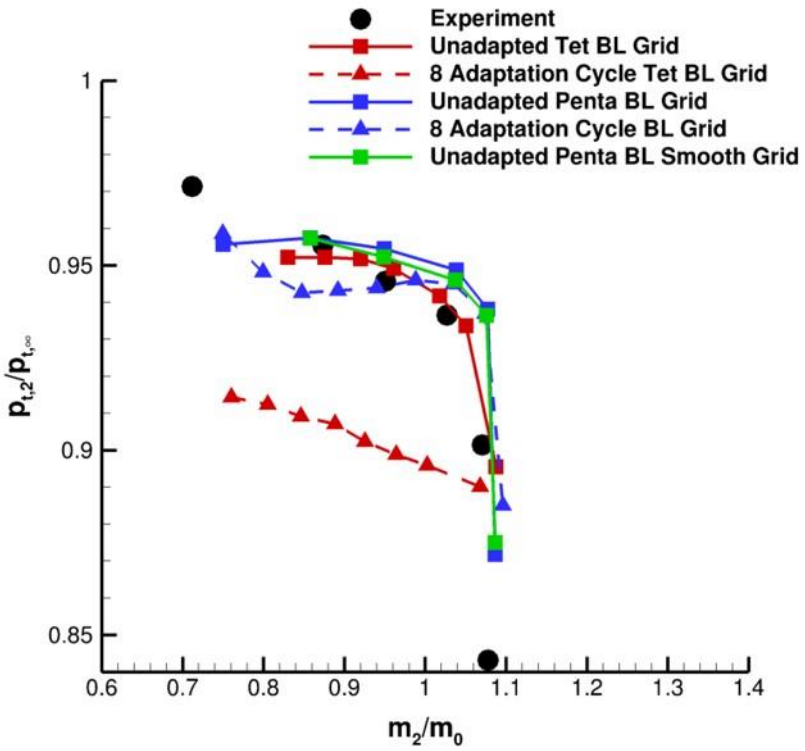
$M_\infty = 1.46$



Inlet circumferential distortion (left) and radial distortion (right)

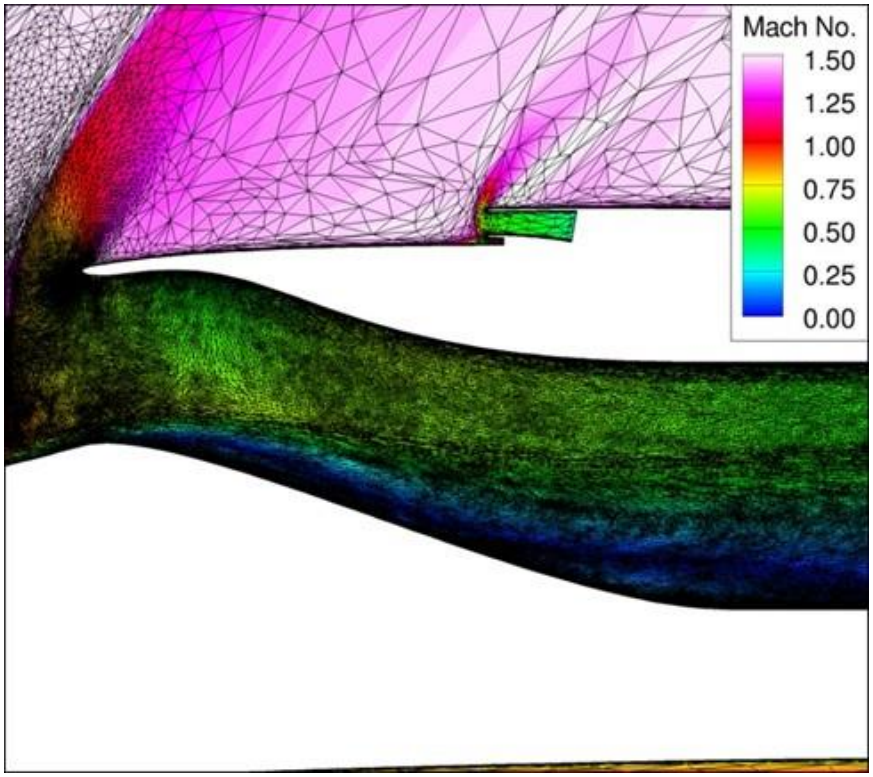
Cell Type and Grid Adaptation Metric

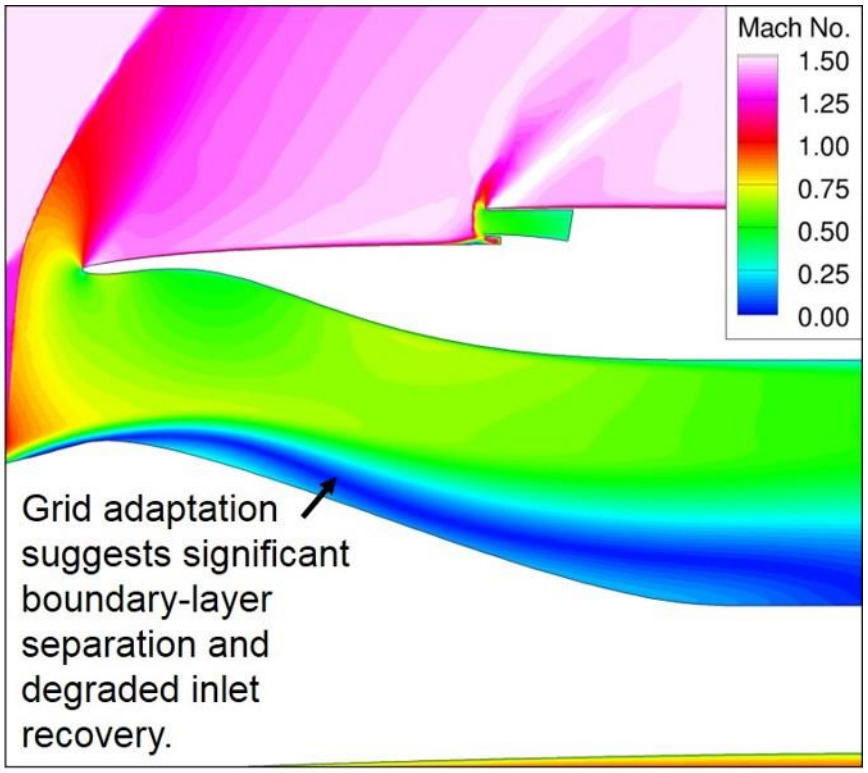
$M_\infty = 1.46$



Number of Adaptation Cycles

$M_\infty = 1.46$



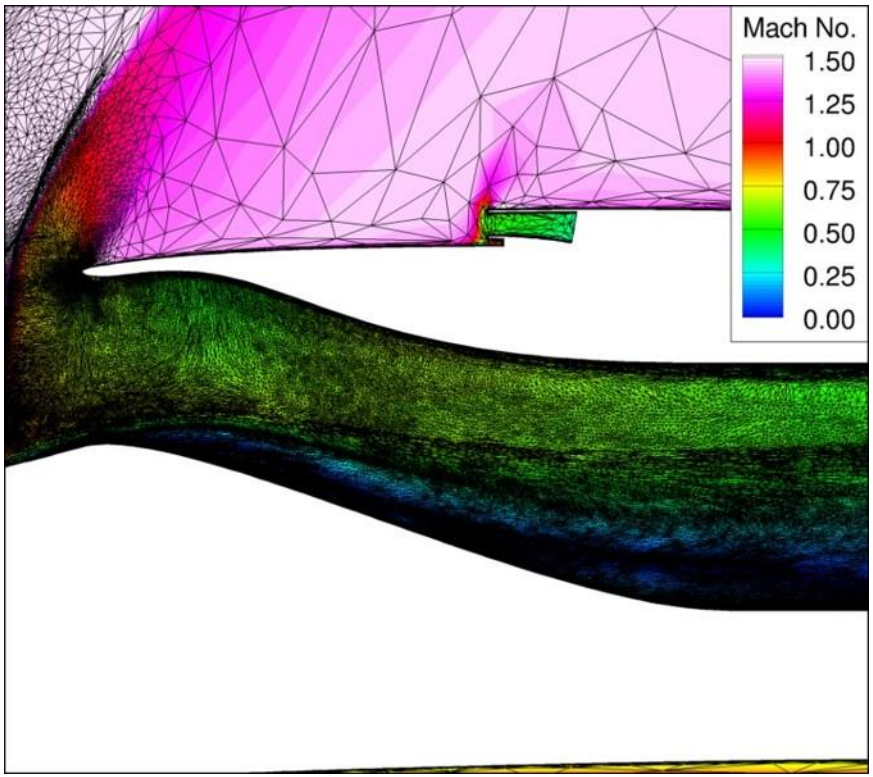


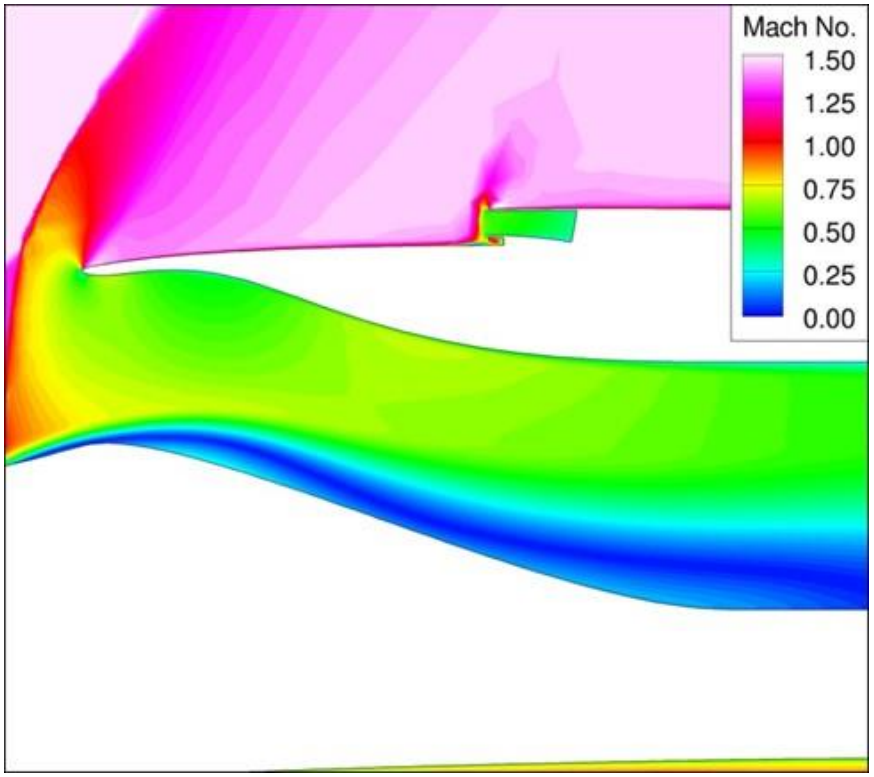
8* adaptation cycle tetrahedral boundary-layer grid (Case #5)
(Pressure Box)

*reduced number of nodes/adaptation cycle.

Number of Adaptation Cycles

$M_\infty = 1.46$



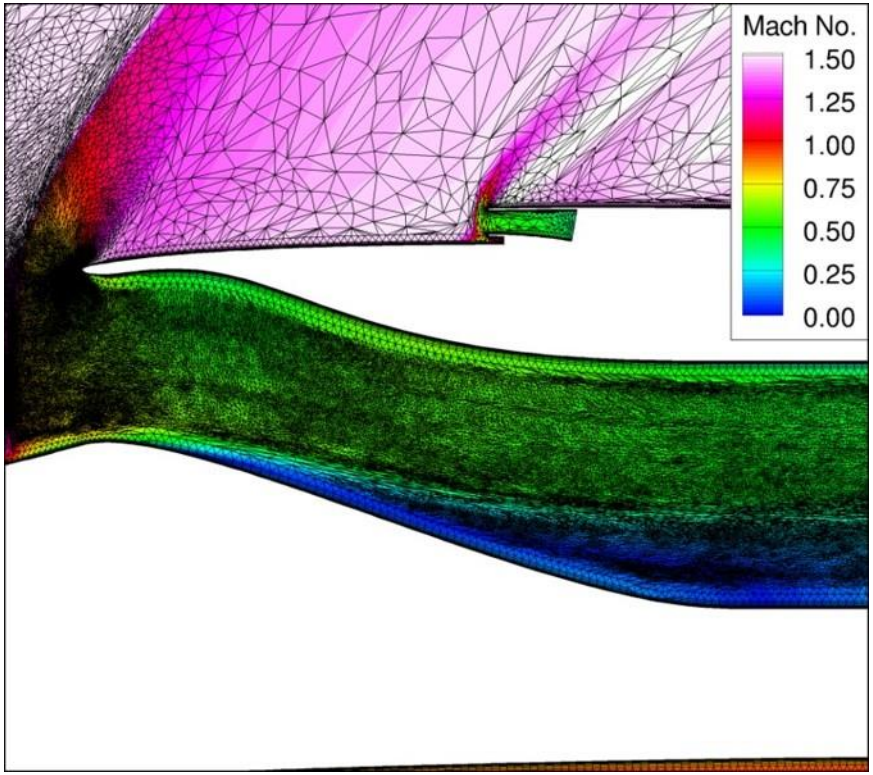


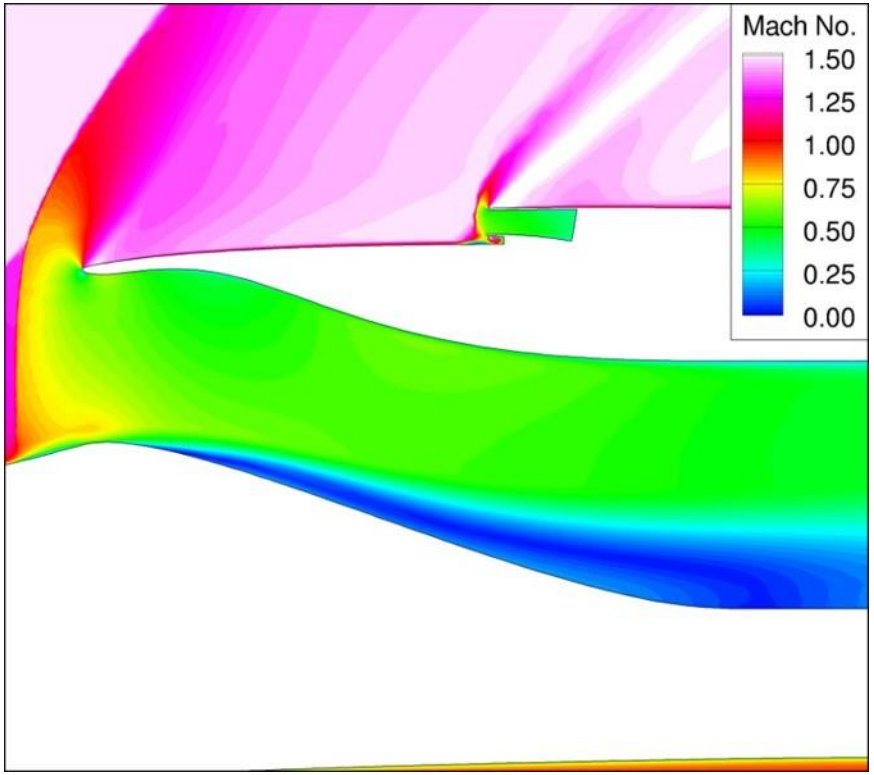
16* adaptation cycle tetrahedral boundary-layer grid (Case #6)
(Pressure Box)

*reduced number of nodes/adaptation cycle.

Number of Adaptation Cycles

$M_\infty = 1.46$



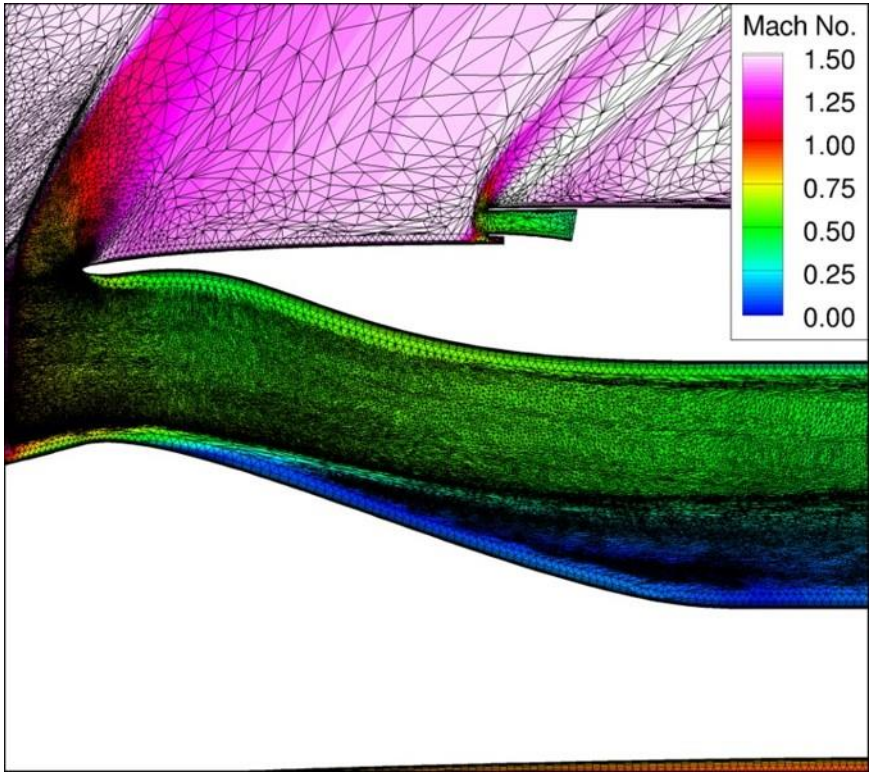


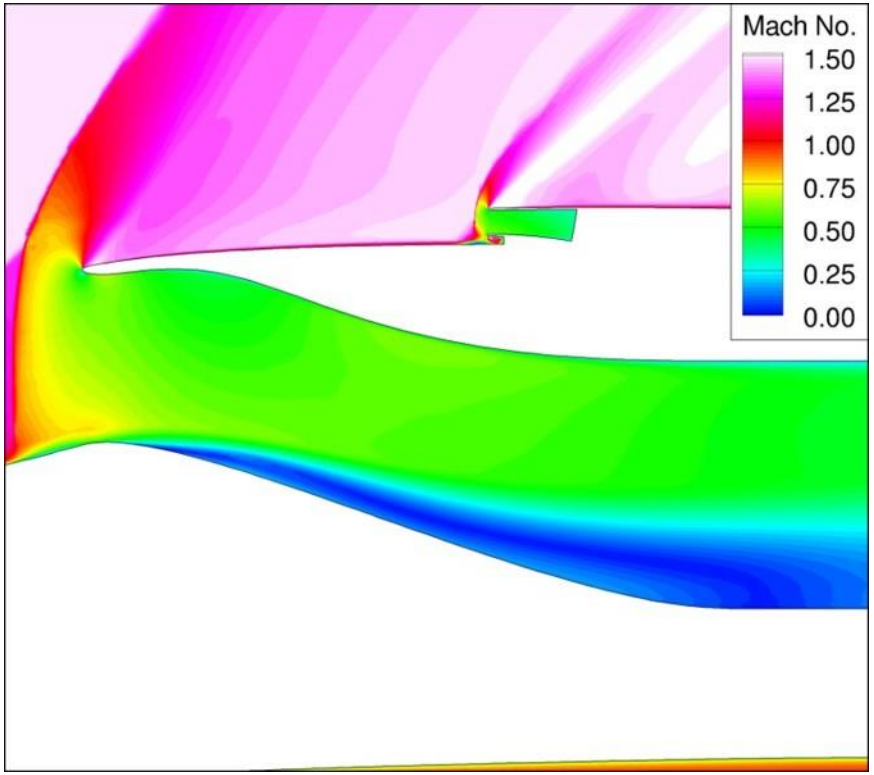
8* adaptation cycle pentahedral boundary-layer grid (Case #7)
(Pressure Box)

*reduced number of nodes/adaptation cycle.

Number of Adaptation Cycles

$M_\infty = 1.46$



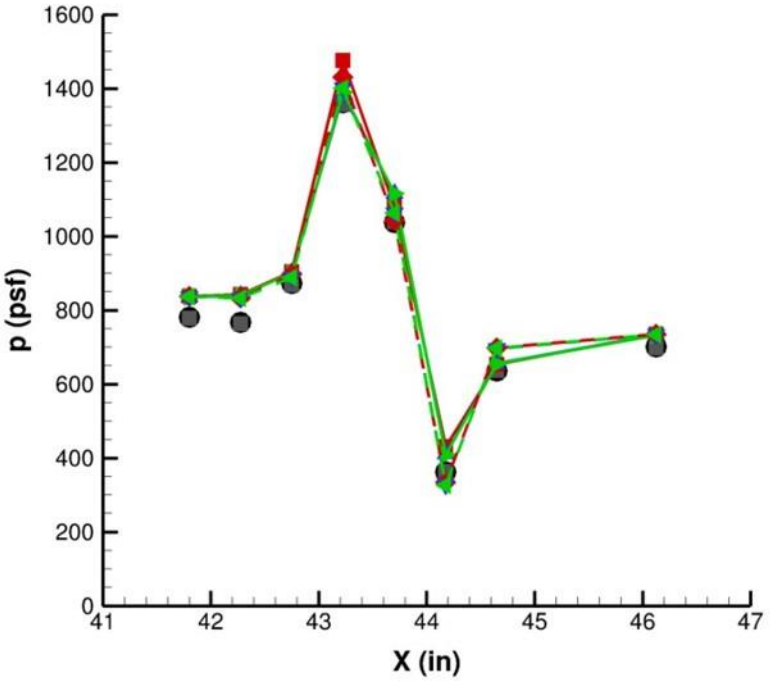


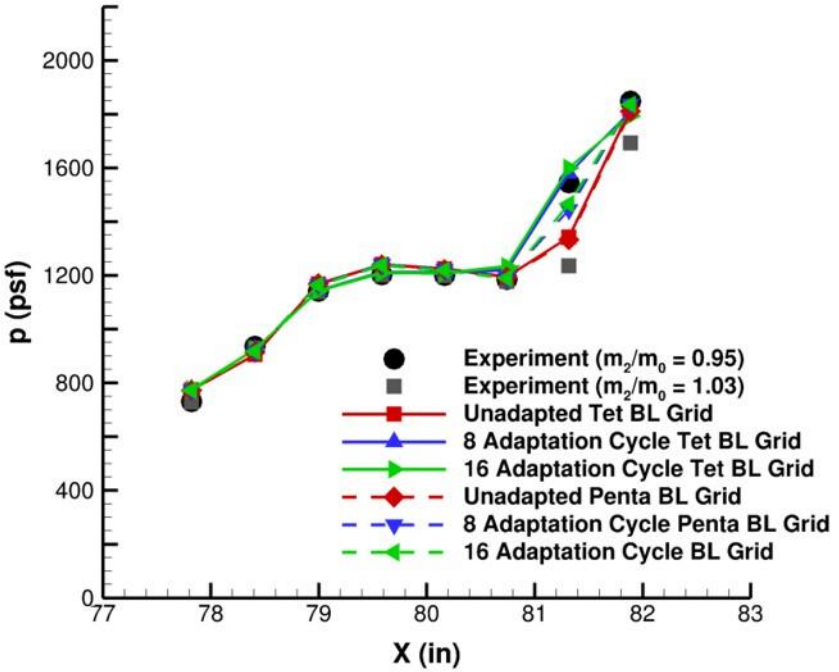
16* adaptation cycle pentahedral boundary-layer grid (Case #8)
(Pressure Box)

*reduced number of nodes/adaptation cycle.

Number of Adaptation Cycles

$M_\infty = 1.46$

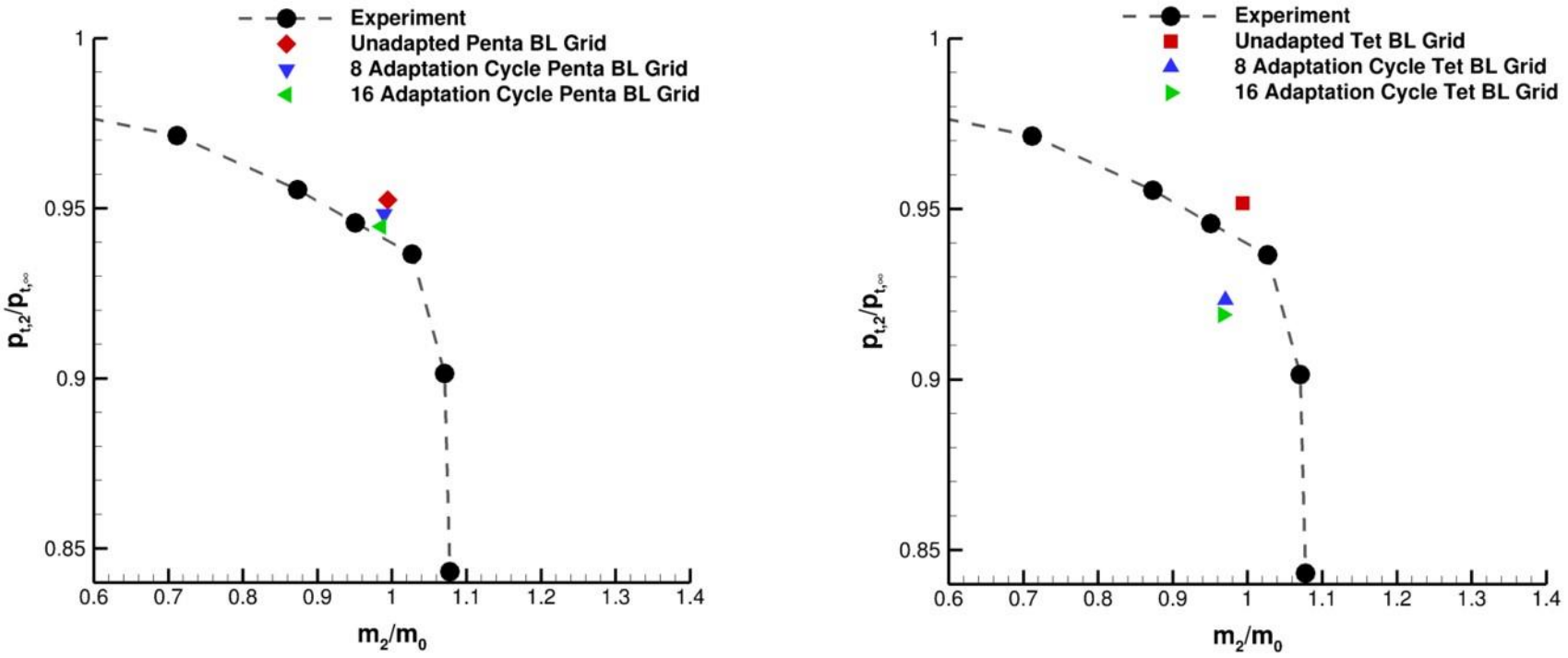




Pressure measurements at the camera fairing (left) and inlet bump (right) regions

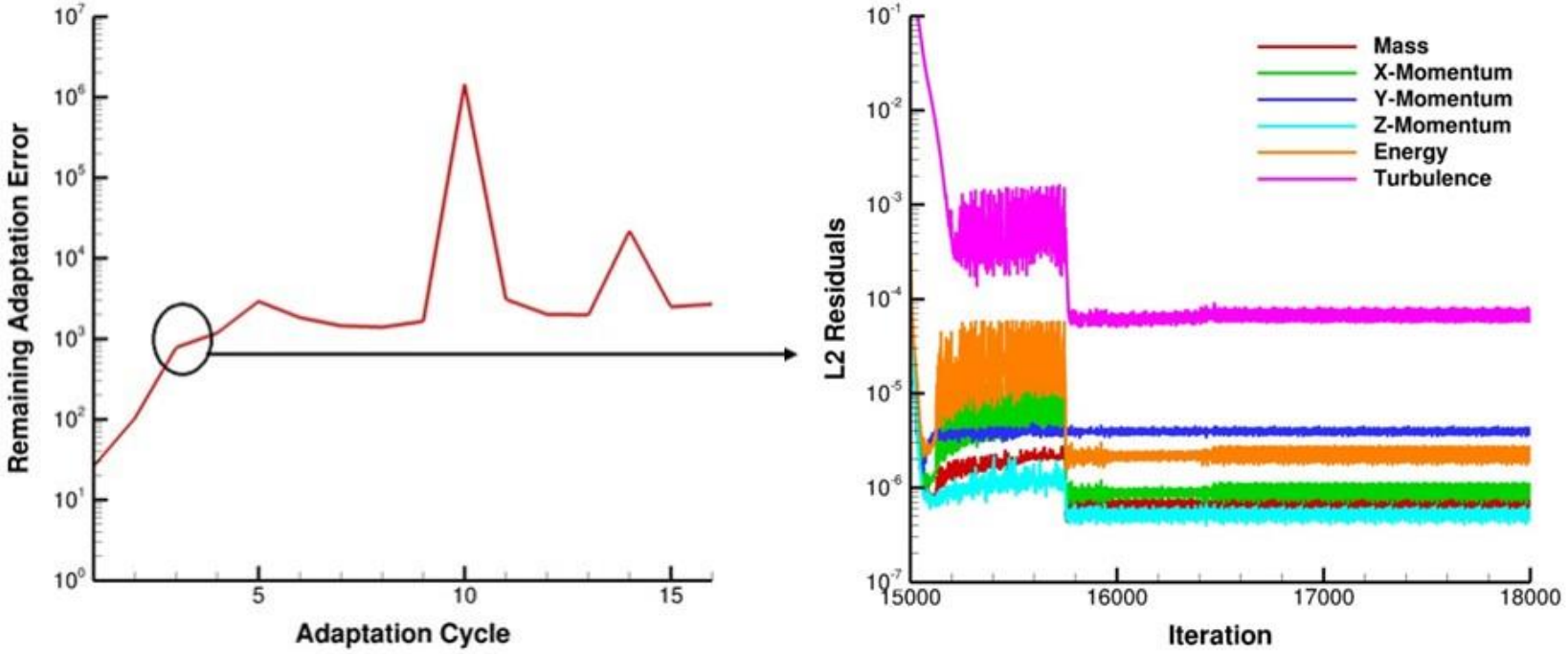
Number of Adaptation Cycles

$M_\infty = 1.46$



40-point total pressure recovery plots for the pentahedral boundary-layer grids (left) and tetrahedral boundary-layer grids (right)

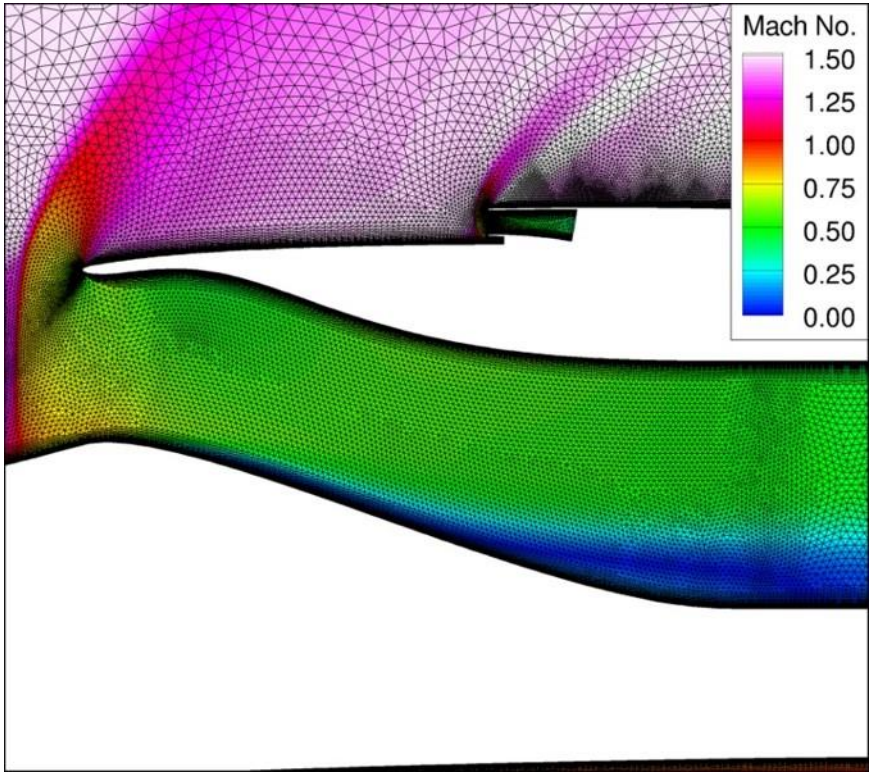
Adaptation Error Estimate

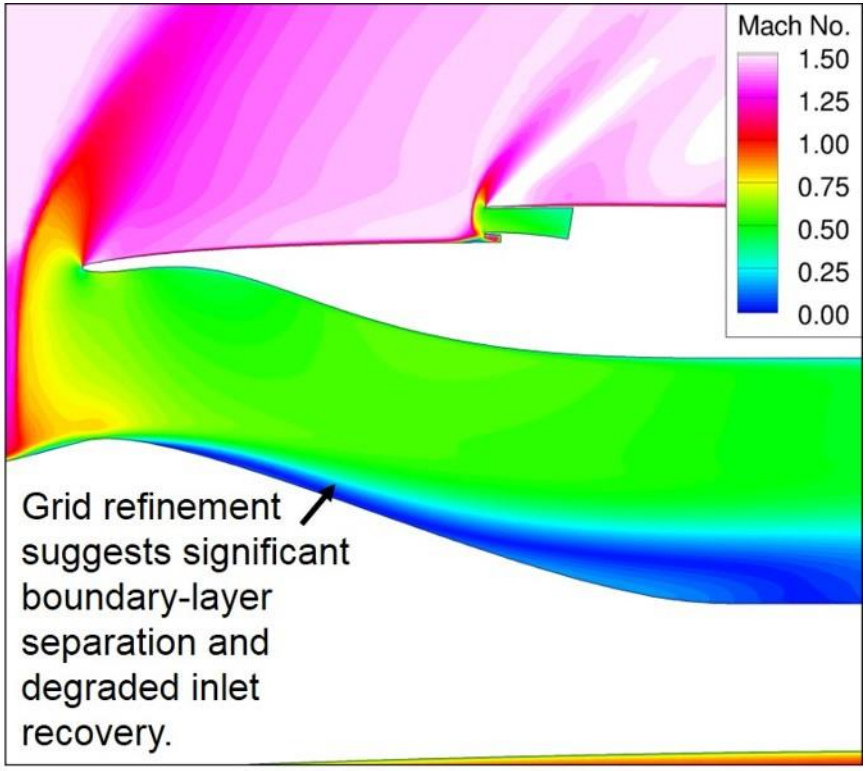


Remaining Adaptation Error = ([Flow Residual Embedded Mesh] x [Adjoint Interpolation Error])
+ ([Adjoint Residual on Embedded Mesh] x [Flow Interpolation Error])

Manually Refined Grids

$M_\infty = 1.46$

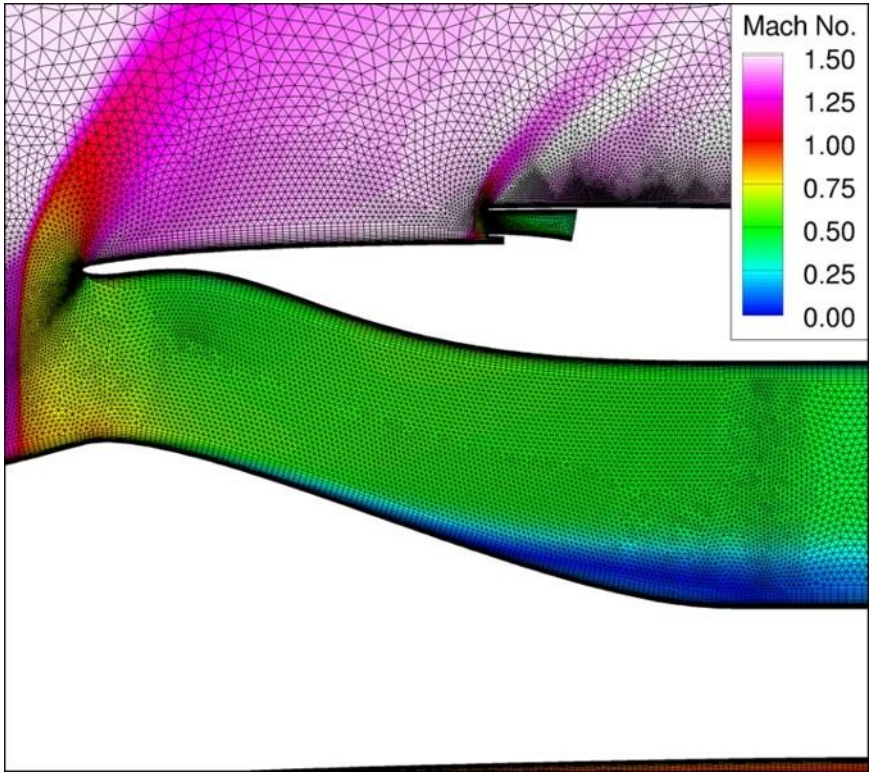


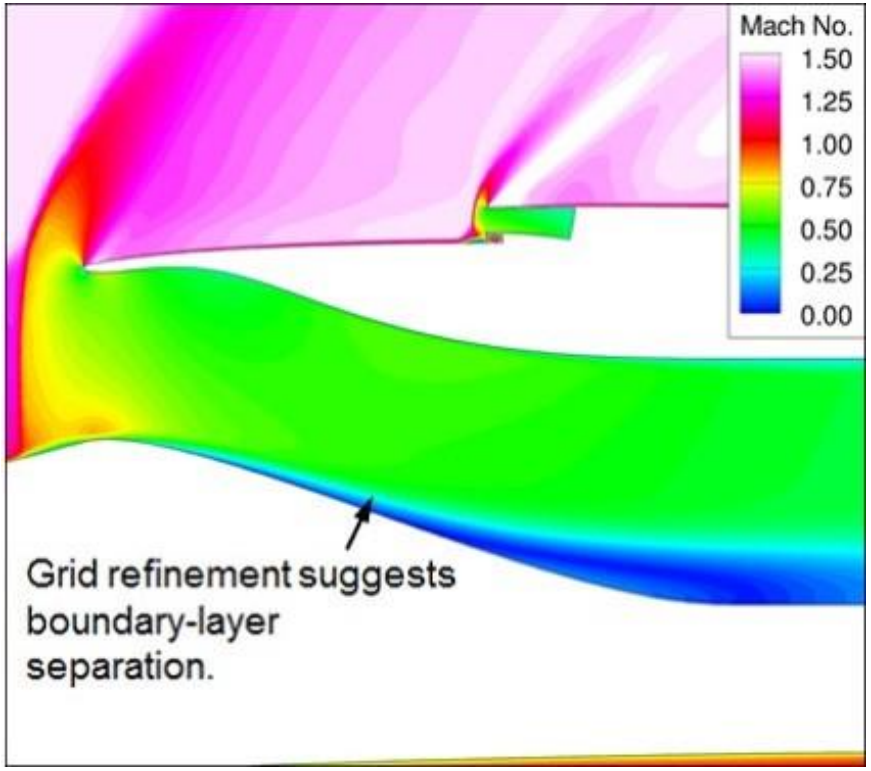


Manually refined tetrahedral boundary-layer grid (Case #9)

Manually Refined Grids

$M_\infty = 1.46$

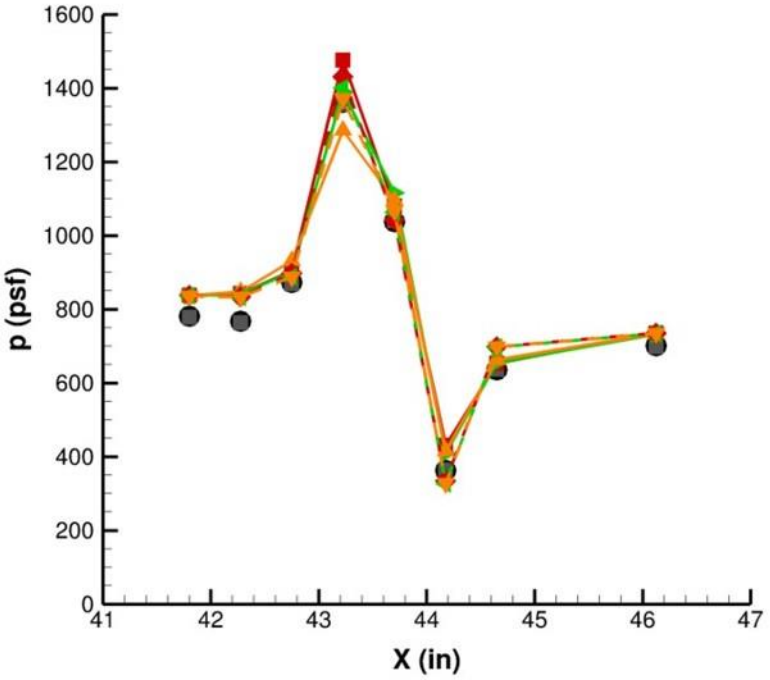


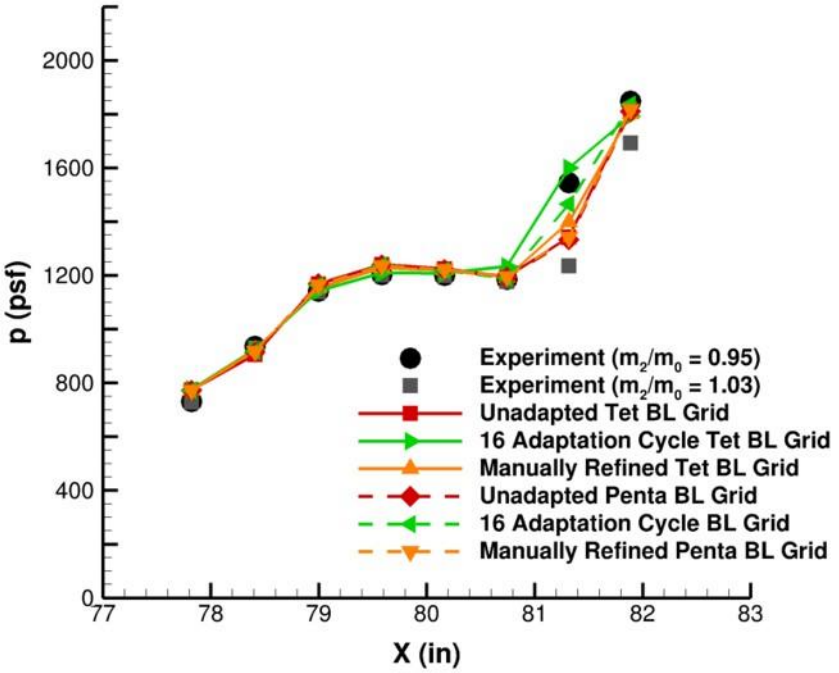


Manually refined pentahedral boundary-layer grid (Case #10)

Manually Refined Grids

$M_\infty = 1.46$

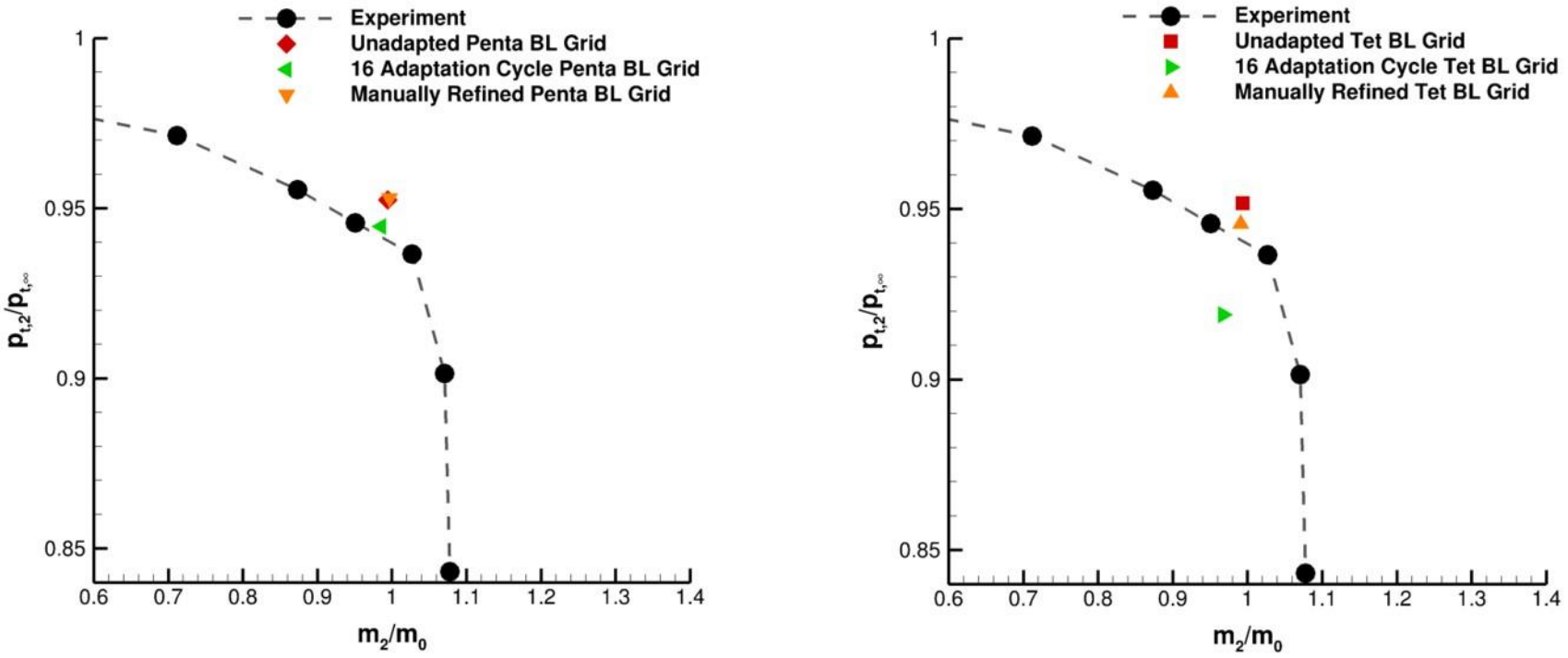




Pressure measurements at the camera fairing (left) and inlet bump (right) regions

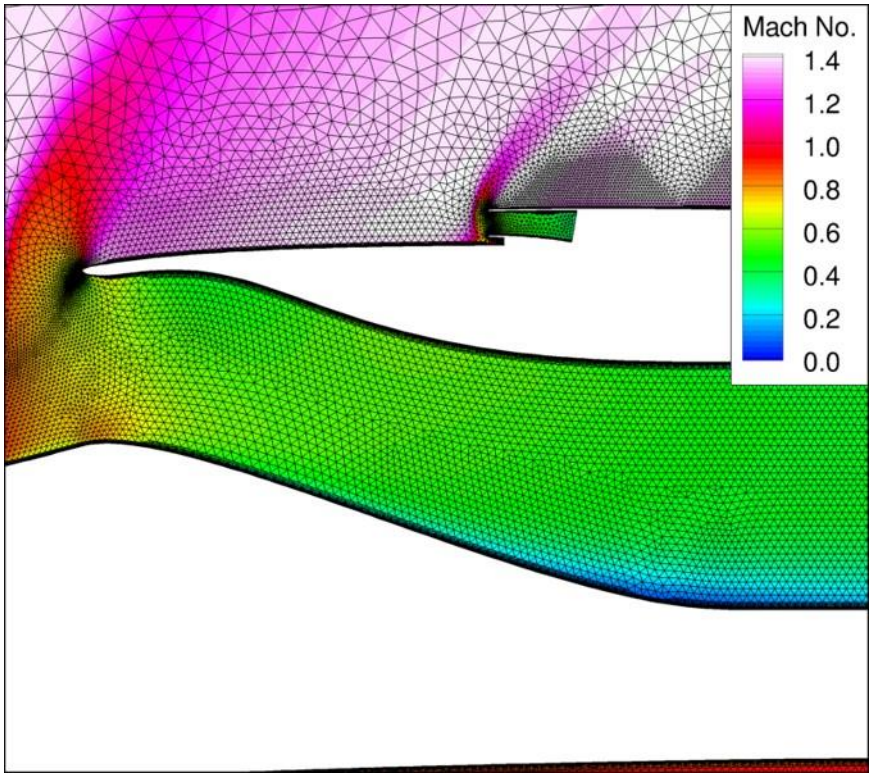
Number of Adaptation Cycles

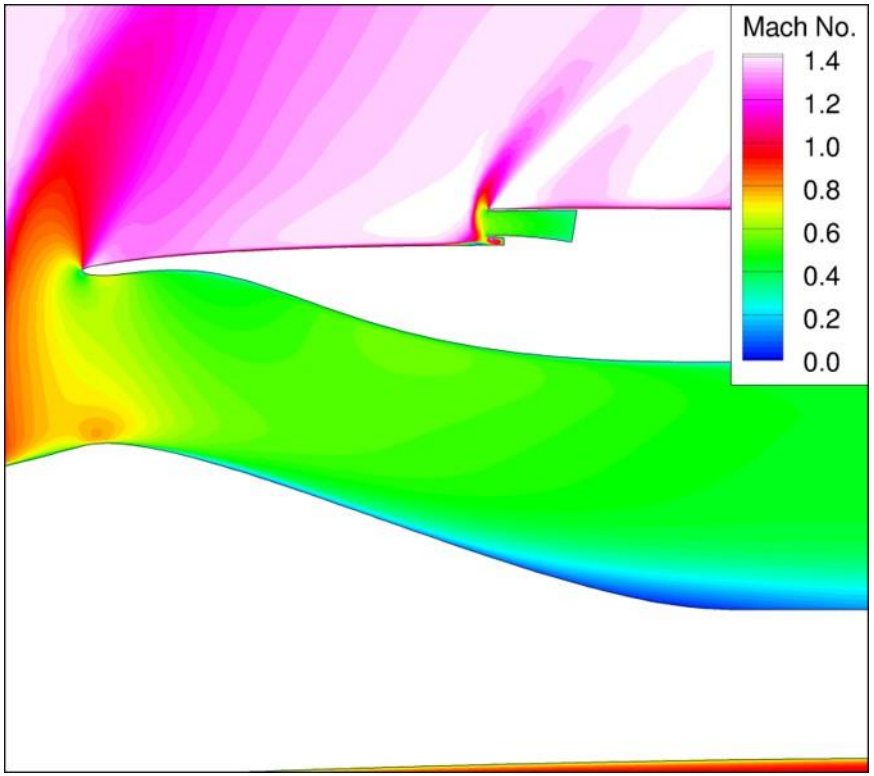
$M_\infty = 1.46$



40-point total pressure recovery plots for the pentahedral boundary-layer grids (left) and tetrahedral boundary-layer grids (right)

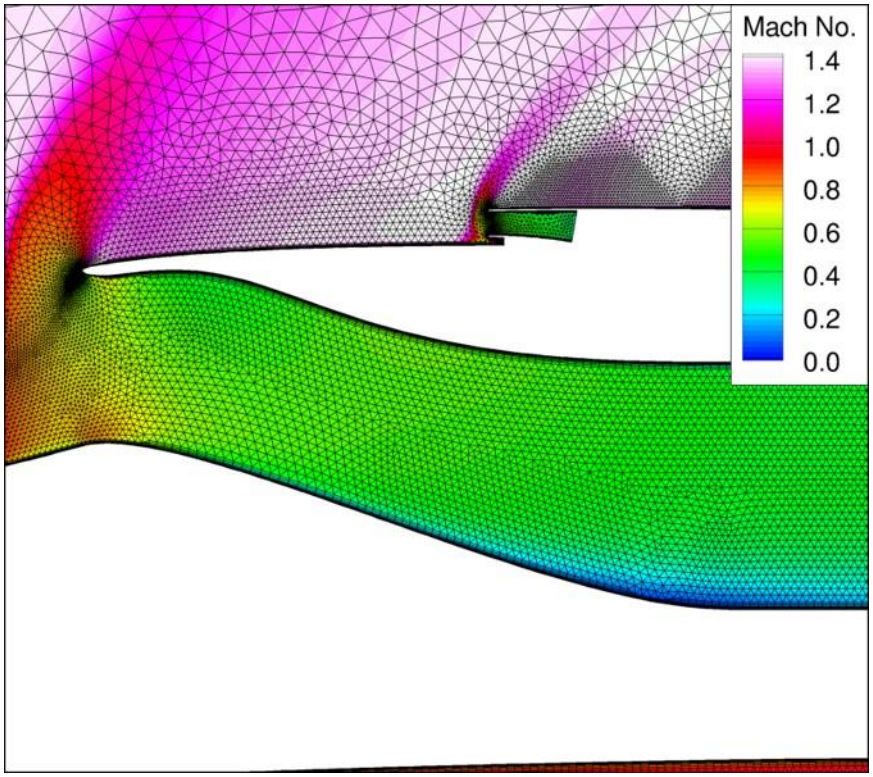
Additional Simulations - $M_\infty = 1.35$

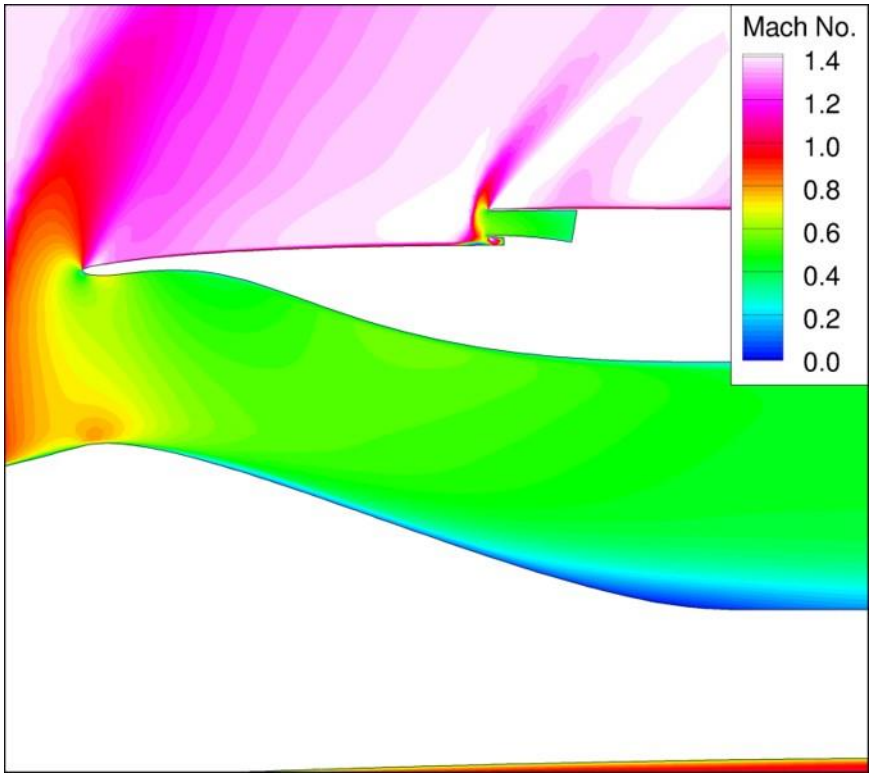




Unadapted tetrahedral boundary-layer grid (Case #1)

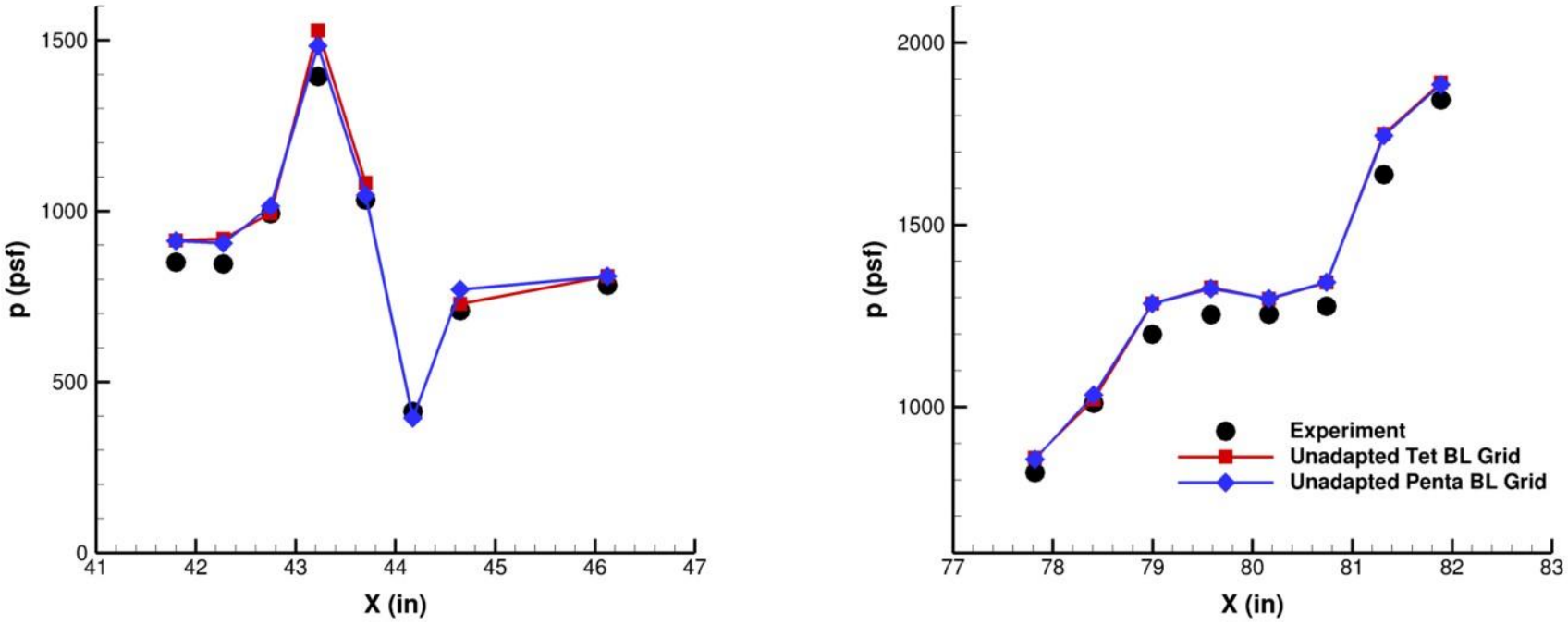
Additional Simulations - $M_\infty = 1.35$





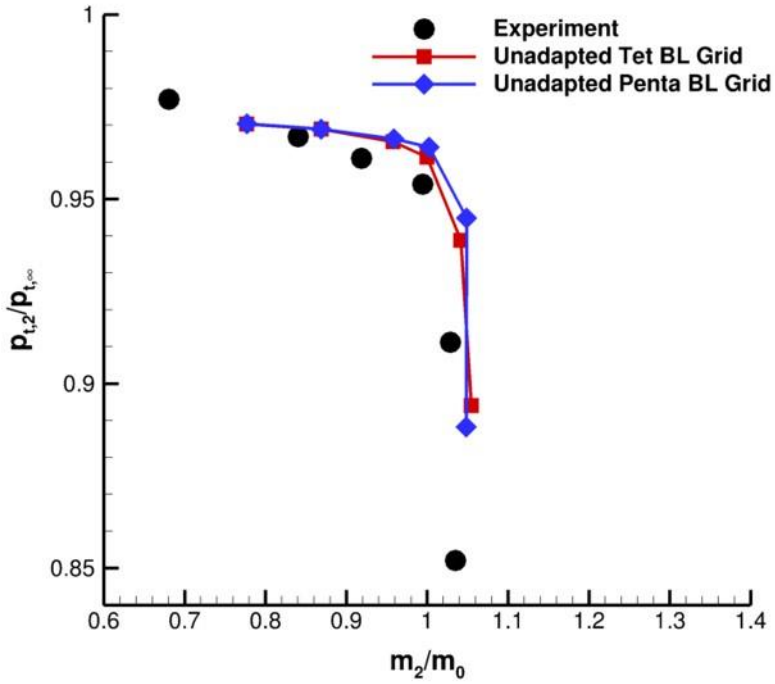
Unadapted pentahedral boundary-layer grid (Case #3)

Additional Simulations - $M_\infty = 1.35$

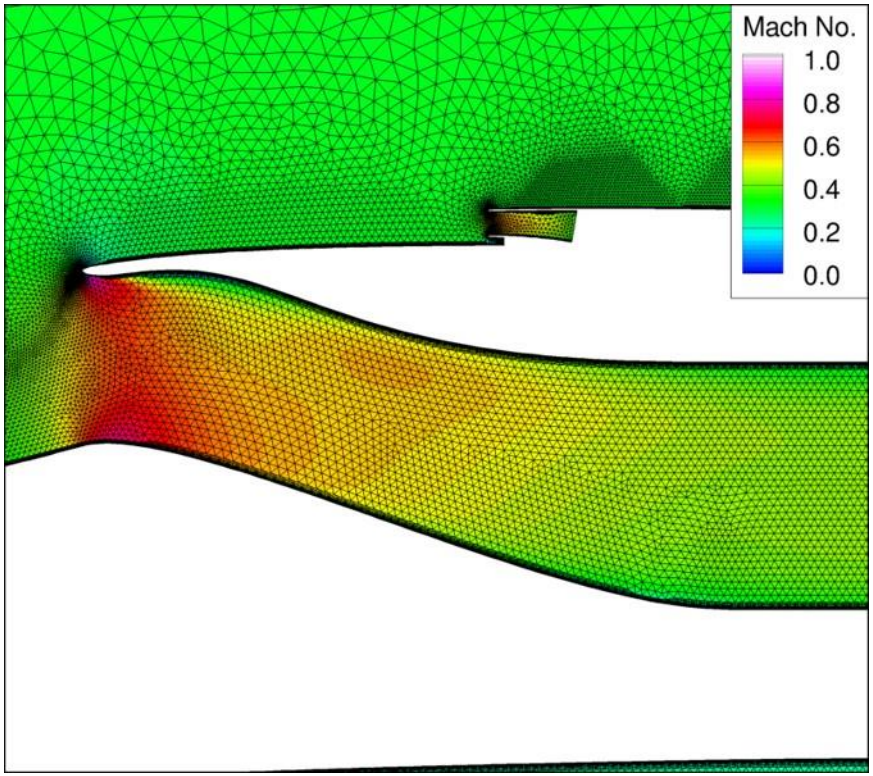


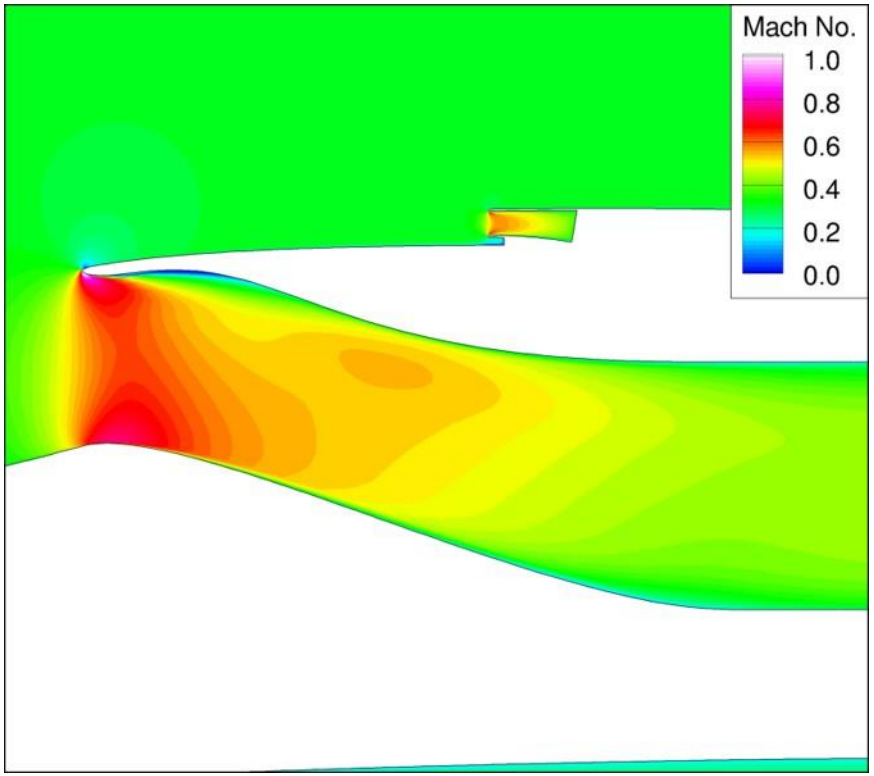
Pressure measurements at the camera fairing (left) and inlet bump (right) regions

Additional Simulations - $M_\infty = 1.35$



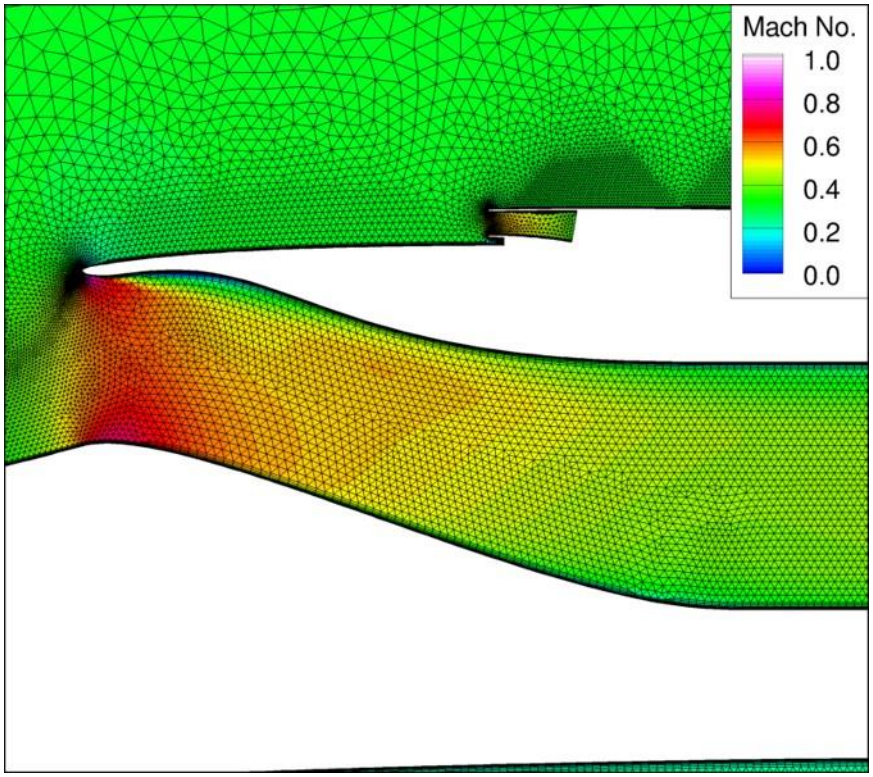
Additional Simulations - $M_\infty = 0.30$

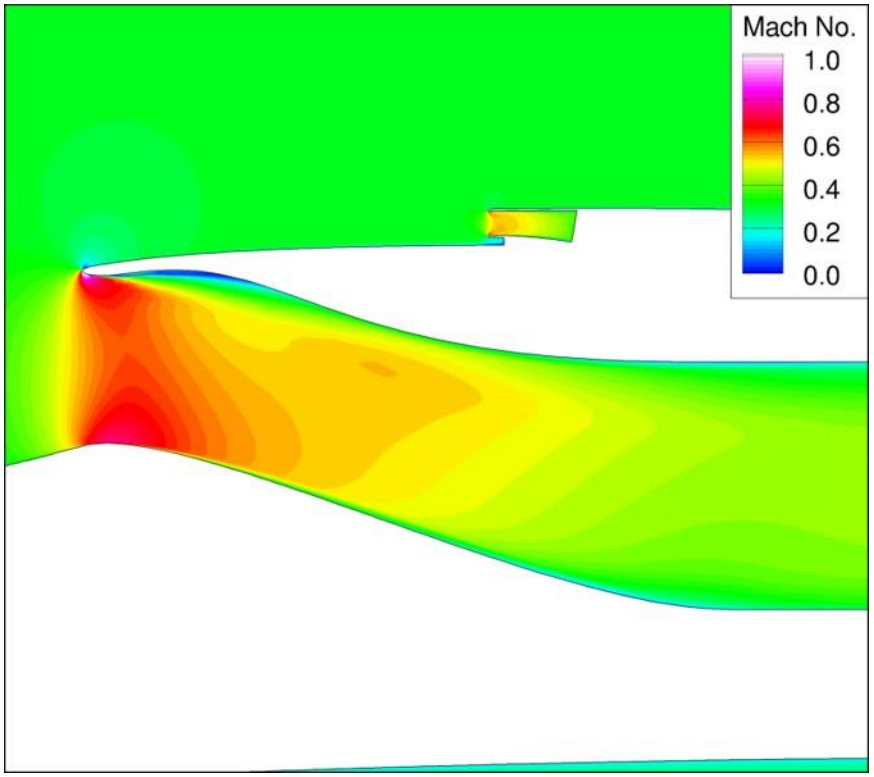




Unadapted tetrahedral boundary-layer grid (Case #1)

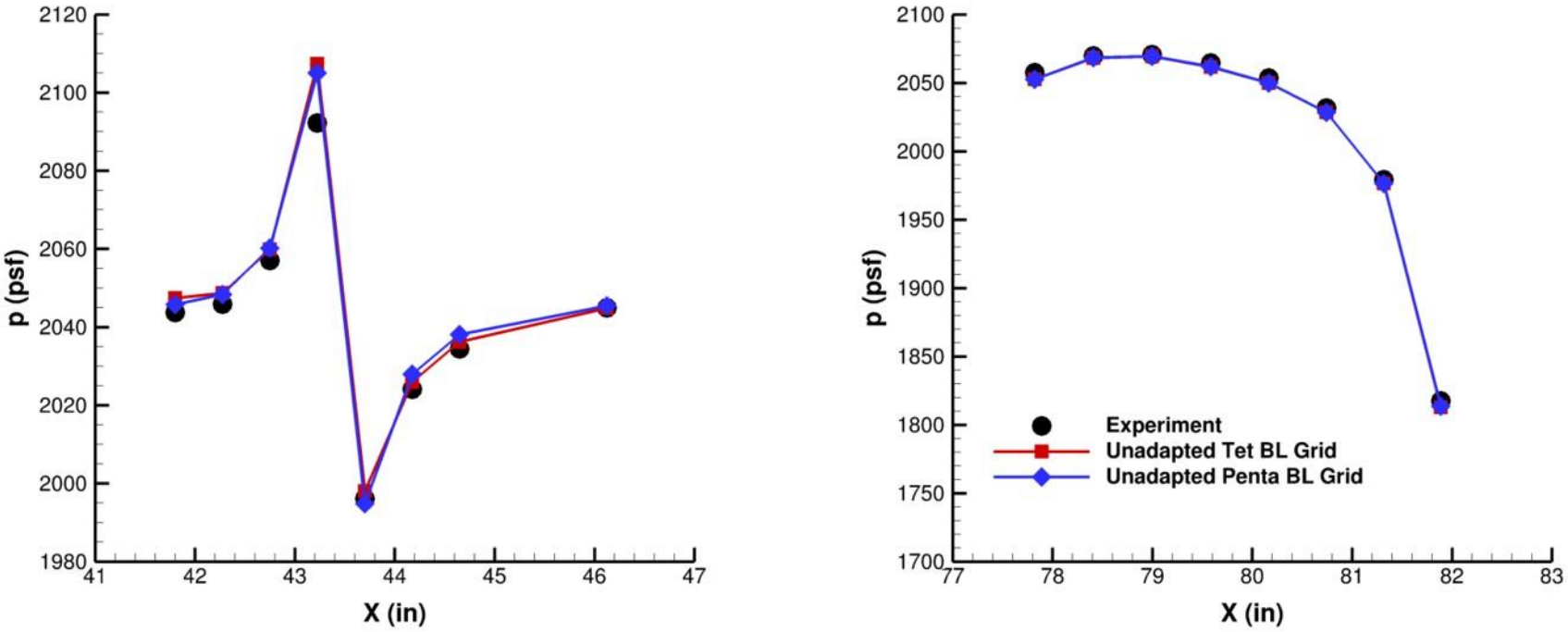
Additional Simulations - $M_\infty = 0.30$





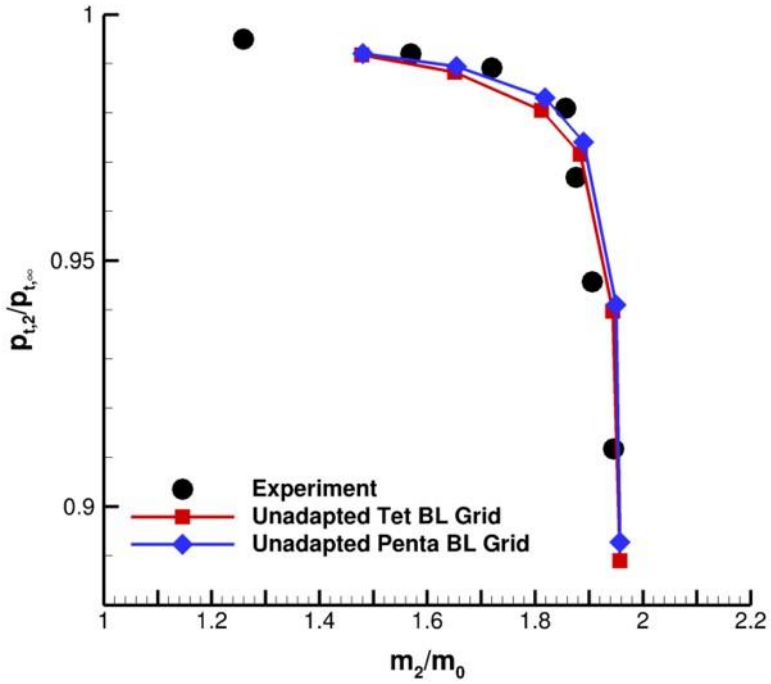
Unadapted pentahedral boundary-layer grid (Case #3)

Additional Simulations - $M_\infty = 0.30$



Pressure measurements at the camera fairing (left) and inlet bump (right) regions

Additional Simulations - $M_\infty = 0.30$



Summary

- A QueSST aircraft preliminary design was simulated using RANS CFD at 9.5% test-scale conditions in order to help determine inlet performance.

Conclusions (Part 1)

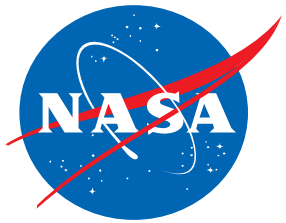
- It was shown that there is a high uncertainty associated with these CFD simulations as they were not shown to be grid independent. This was true regardless of…
  - the type of cells near the boundary-layer regions.
  - whether the adjoint-mesh refinement was used vs. manual grid refinement.
  - the number of adaptation refinement cycles.
  - the adaptation metric used.

Conclusions (Part 2)

- There is a high uncertainty in the CFD simulations if a grid refinement study is not performed or if the simulations are not anchored to experimental data.

Acknowledgements

- The NASA Commercial Supersonic Technology Project for funding.
- The NASA High End Computing Program for super-computing resources.
- Mike Park for guidance on the grid adaptation process.

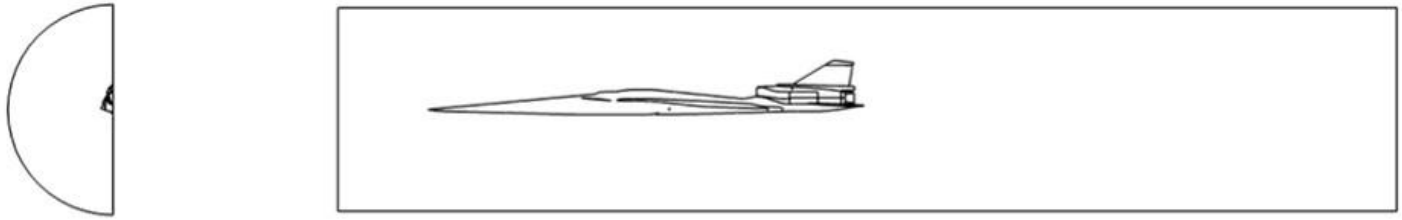

NASA

Backup

Boundary Condition

- Inlet:
  - Mass flow through the inlet was set by setting the average Mach number at the inlet exit plane.

Example Domain



Front View

Side View